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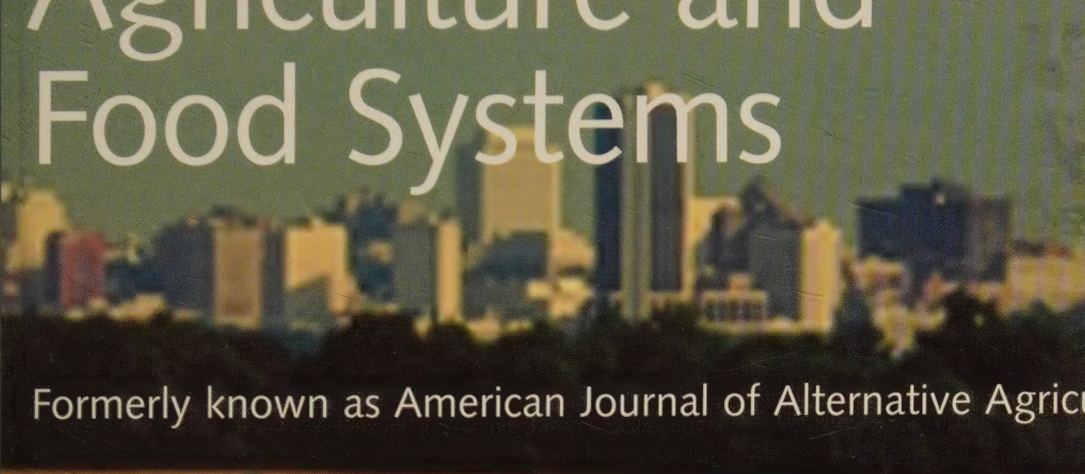
Renewable Agriculture and Food Systems



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Renewable Agriculture and Food Systems

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Renewable Agriculture and Food Systems provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.

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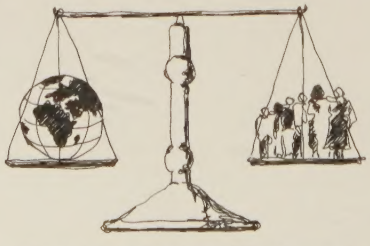

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Renewable Agriculture and Food Systems

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CAB International
Wallingford
Oxon OX10 8DE
UK
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Urban organic farming in Austria with the concept of *Selbsternte* ('self-harvest'): An agronomic and socio-economic analysis

Christian R. Vogl*, Paul Axmann, and Brigitte Vogl-Lukasser

Institute for Organic Farming, University for Natural Resources and Applied Life Sciences Vienna, Gregor Mendel Strasse 33, A–1180 Vienna, Austria.
*Corresponding author: vogl@edv1.boku.ac.at

Accepted 23 September 2003 **Research Paper**

Abstract

In Vienna, consultants, organic farmers and green-minded consumers have developed a new concept of urban organic farming, called *Selbsternte* ('self-harvest'). Organic farmers prepare a plot of arable land (the *Selbsternte* plot) and sow or plant rows composed of 18–23 plant species. In mid-May the plots are divided into subplots that contain 2–6 m of every sown species and are rented to so-called self-harvesters for a period of about 136 days. In 2002 *Selbsternte* was being practiced at 15 plots in Vienna or in neighboring cities, represented by 861 subplots, with a total area of 68,740 m^2, and managed by 12 organic farmers for 861 registered self-harvesters. At the Roter Berg plot, experimental subplots were established to evaluate yields and the value of the harvested produce, and interviews were conducted with 27 self-harvesters, the eight *Selbsternte* farmers and one *Selbsternte* consultant. The experimental subplots were managed in two different ways, namely, 'with low intensity' (LIS) and 'with high intensity' (HIS; meaning additional harrowing, mulching and sowing of additional plants). At the LIS 24.2 h and at the HIS 38.9 h of work were invested over 51 days. Monetary investment was US$184 for the LIS and US$259 for the HIS subplots. The total harvest of fresh produce was: 163 kg $subplot^{-1}$ for LIS and 208 kg $subplot^{-1}$ for HIS subplots. The total value of the harvest at the HIS was US$364 for conventional and US$766 for organic prices. All self-harvesters saw the rental of a subplot and the work as an activity of leisure. More than half of the self-harvesters reported 'trying something new' at their subplots. The most frequently mentioned innovation for them was growing an unknown species. Twenty-five self-harvesters sowed 54 different, additional plant species. The motivating factors in establishing *Selbsternte* plots, as reported by all the farmers, were, primarily, better relations with consumers and work diversification, and only then were economic factors a consideration. The contribution of *Selbsternte* to income varied at the farms, being between 0 and 30% of the total farm income. As a main success factor, all of the farmers reported a close relationship between the self-harvesters and the farmers. *Selbsternte* subplots can be understood as small experimental stations where self-harvesters merge traditional horticultural techniques with urban ideas on permaculture, sustainable land use and participatory farming. *Selbsternte* has potential value for the improvement of urban agriculture, but also for the development of organic farming in general.

Key words: urban farming, organic farming, agrobiodiversity, innovation, self-harvesters relations, farmers' experiments

Introduction

Cities like Vienna (Austria) are known for their great monuments and wonderful fine arts. At first glance, Viennese urban agriculture seems to be limited to public baroque gardens, vineyards, allotments (*Schrebergärten*) and intensive vegetable cultivation in the district called *Simmering*. But recently, consultants, organic farmers and green-minded self-harvesters have developed a new concept of urban organic farming, called *Selbsternte* ('self-harvest'), which allows new types of interaction between organic farmers and urban citizens in residential areas. The aim of this paper is to describe the concept, to characterize the self-harvesters and organic farmers involved, to assess

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the agronomic and socio-economic benefits and the possible constraints of the concept, and to develop hypotheses for further research.

The effort to extend urban farming in Vienna parallels similar efforts in other countries worldwide. The worldwide trend towards urbanization and the pressure to develop agricultural land in cities and their peripheries into new residential areas, industrial facilities or shopping malls has led to counter efforts. Such efforts aim to safeguard green urban areas by designating at least some of them for agricultural use[1,2].

About 800 million people farm in urban settings worldwide[3]. The farmers, consumers, urban planners and scientists dealing with urban farming expect this kind of urban land use to lead to better food security, nutrition and health, to improve the social development of neighborhoods, and to raise the sustainability of cities by reducing their ecological footprint[4–6]. Urban farming is not only promoted in developing countries but also in cities like New York[7], Berlin[8], Tokyo[9], London[10] and Vienna (see below), where these positive effects also are expected. Some authors believe that using organic practices increases the sustainability of urban agriculture[11,12].

The concept of Selbsternte

When utilizing the *Selbsternte* system, organic farmers (organic in accordance with European Council Regulation No. 2092/91) prepare a parcel of arable land in the urban area, owned by themselves or rented to them by a third party, by tillage, fertilization and construction of fencing and irrigation facilities. The shape of this piece of land for *Selbsternte* is usually rectangular and it is herein called a *Selbsternte* plot (Fig. 1). At their *Selbsternte* plots, the farmers sow or plant rows with different vegetable species, subspecies or varieties, all referred to henceforth as *species*. Eighteen to twenty-three species can be found at these *Selbsternte* plots. Between 1 and 4 rows are sown for each species. In mid-May, the plots are divided into subplots of 20, 40, 60 or 80 m^2 (Fig. 1, Fig. 2). Subplots are situated with the longer edge of the subplot in a pattern perpendicular to the direction of the rows, so that each subplot contains 2–6 m of every sown species, or more in cases when one species is grown in more than one row (see an example of a subplot and its species in Fig. 2). Then subplots are rented to self-harvesters for between US$73 and US$182 (calculation based upon the exchange rate: 1 euro = 1 US$) in total, for the time between May and October. The price of the rental fee depends on the size of the subplot and the additional management offered by the farmer (irrigation, weeding, winter storage of produce, additional plots for flowers and spices, etc.). In November the self-harvesters have to leave the subplots and the organic farmers proceed with soil management for succeeding agricultural crops or for the next *Selbsternte* period.

The sequence of work (Fig. 3) as described above is called *Selbsternte*, literally: 'harvest by ourselves'. But

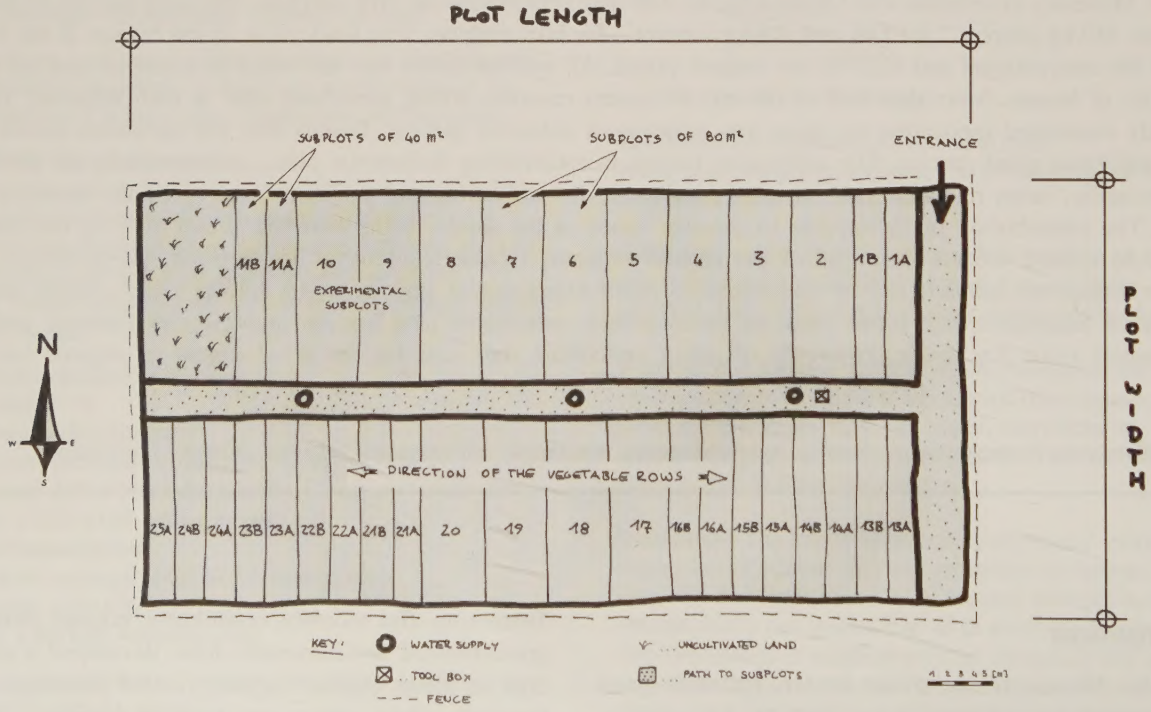
PLOT LENGTH
SUBPLOTS OF 40 m²
SUBPLOTS OF 80 m²
ENTRANCE
11B 11A 10 9 8 7 6 5 4 3 2 1B 1A
EXPERIMENTAL SUBPLOTS
N
DIRECTION OF THE VEGETABLE ROWS
25A 24B 24A 23B 23A 22B 22A 21B 21A 20 19 18 17 16B 16A 15B 15A 14B 14A 13B 13A
PLOT WIDTH
KEY:
WATER SUPPLY
UNCULTIVATED LAND
TOOL BOX
PATH TO SUBPLOTS
FENCE

Figure 1. The *Selbsternte* plot Roter Berg, Vienna, with the self-harvesters' subplots of different size (40 m^2, 80 m^2) and the two experimental subplots (subplot 10, managed with high intensity, HIS; and subplot 9, managed with low intensity, LIS). Plant species were sown from right to left and vice versa.

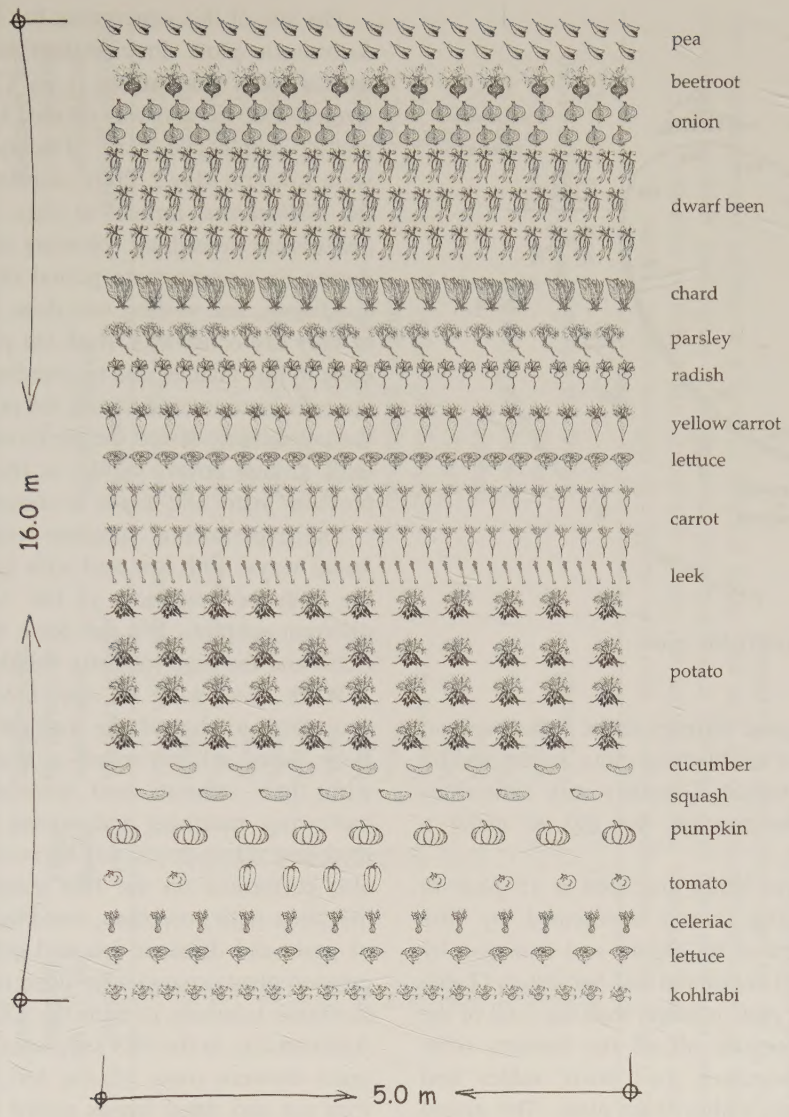

Figure 2. A scheme of a *Selbsternte* subplot as rented by a self-harvester with the choice of plant species usually sown/planted by *Selbsternte* farmers.

Selbsternte is not only the technical term for the concept; it is also a registered logo and text trade mark for the Selbsternte company that provides the *Selbsternte* trade label to farmers and that supports all participating farmers and self-harvesters with necessary technical information. Consultants of the Selbsternte company advertise the concept, and are engaged in the organization of courses for self-harvesters on organic farming, on healthy cooking and on several related topics. Farmers using the trade mark and receiving consultancy pay an annual license fee (between US$185 and US$810, depending on the number of the subplots) to the Selbsternte company.

A brief history of how the idea spread

The first *Selbsternte* plot was established by the organic farmer Rudolf Hascha in Rothneusidel (10th District of Vienna) in 1987. He obtained support for his idea from the Department for Environmental Advice (Mrs Bruno, Environmental Advisory Service) in Vienna. As a result of the farmers' and self-harvesters' positive experience, the Municipality of Vienna decided to establish another *Selbsternte* plot at the municipal farm Schafflerhof. Due to intense public relations activity, even more plots were established by other farmers between 1994 and 1996.

Mrs Bruno and Mr Resch, an organic farmer, founded the company Selbsternte in 1998 to fully support the idea. The company itself started to manage *Selbsternte* plots. Since 2002, the Municipal Department for Gardens and Parks (*MA 49*) and teachers and students of the technical school for gardening in Vienna (Gartenbauschule Schönbrunn) have been supporting the management of some plots.

Recently, the University of Kassel-Witzenhausen in Germany learned of the concept. They established plots at their experimental farm and advertised the concept. As a

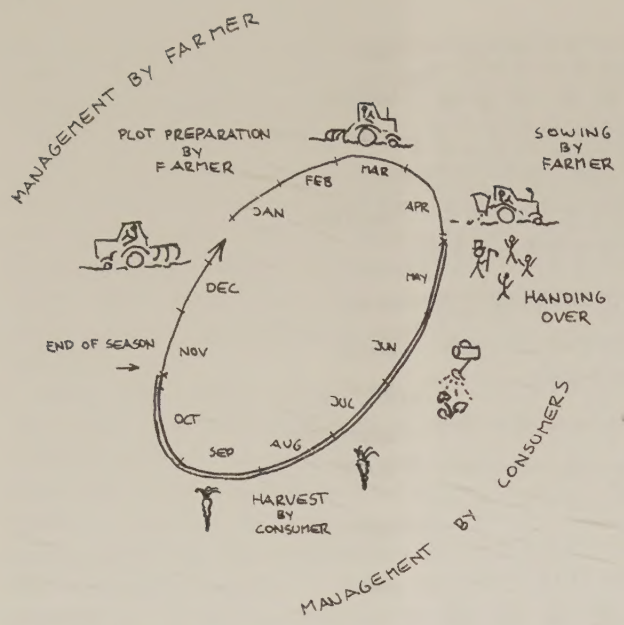

Figure 3. The *Selbsternte* yearly life cycle.

consequence, several organic farmers in the region around Witzenhausen also started establishing plots, supervised by this university[13,14]. In Munich, Germany, city authorities also started applying the concept, but did so under a different name.

In 2002 *Selbsternte* was being practiced at 15 plots in Vienna or in neighboring cities, represented by 861 subplots, with a total area of 68,740 m^2 and managed by 12 organic farmers for 861 registered self-harvesters (Table 1). The actual area of the plots is larger than the total of the area of the subplots, because all of the farmers offer additional areas for recreation, i.e., lawn, tables and benches, and playgrounds within their plots. The actual number of self-harvesters working in subplots is larger than the number of registered self-harvesters, because all registered self-harvesters work together with friends and relatives at the subplots.

Methods

To assess the benefits and constraints of the *Selbsternte* concept, experimental subplots were established to evaluate the yields and net profit for the self-harvesters, and interviews were conducted with the self-harvesters, the *Selbsternte* farmers and one *Selbsternte* consultant.

Survey at the experimental subplots

Two subplots (Fig. 1) at the *Selbsternte* plot Roter Berg were managed between May and October 2001. The experimental management started on May 18, 2001, when all subplots were handed over to the self-harvesters, and ended on October 31, 2001, when subplots had to be returned to the farmer.

The site of this experiment has been used since 1999 for *Selbsternte* plots. Precipitation is 613 mm $year^{-1}$ and the annual mean temperature is 9.9°C. In 2001 the plot had a size of 3000 m^2 and was divided into 13 subplots of 80 m^2 and 21 subplots of 40 m^2. Twenty plant species (Table 2) were sown on May 2, 2001, or planted on May 17, 2001, by the *Selbsternte* farmer at this site. According to the *Selbsternte* consultant, plowing at Roter Berg was done during an inappropriate period of excessively humid soil conditions, and sowing was done subsequently in a period of very dry conditions. Both the plowing and sowing were done in this manner due to coordination problems and time pressure encountered during the project. As a consequence, the consultant viewed the performance of the plants (time until ground cover, yields) at this plot as worse than in previous years and worse in comparison to other plots.

The experimental subplots were managed in two different ways: with low and with high intensity—representing both the gradations of the 'intensity' factor—at two different subplots. We call them the low-intensity subplot (LIS) and the high-intensity subplot (HIS).

Work was done on the LIS subplot in a manner equivalent to that of the average self-harvester at Roter Berg. Some self-harvesters at Roter Berg took extra care with their subplots and introduced practices such as harrowing, mulching and sowing of additional plants. To represent this type of self-harvester, these activities were also performed on the HIS subplot. As a consequence, irrigation with hosepipes, weeding and the manual control of pests and diseases (manual collecting of pests and of infested plant organs) were done in the same way and with the same intensity in both the LIS and the HIS subplots. Additionally, in the HIS subplot: (1) soil was harrowed six times between rows; (2) the soil was mulched five times with cut and dried weeds pulled from the paths; and (3) additional plants were sown or planted between May and October. These additional plants consisted of individuals of the species already present, i.e., species sown or planted by the farmer, and individuals of species new to the plot, i.e., species introduced by the self-harvesters.

During management, inputs (cash to cover the necessary costs, duration of work) and the output (fresh weight of all harvested produce) were surveyed on data sheets. Only those costs related directly to the management of the subplot were recorded (rental fee, cost of seeds and plantlets, materials necessary to manage the subplot), i.e., neither the cost of transport incurred in buying necessary inputs, harvest processing costs nor cooking costs were recorded. Duration of work was recorded in the categories of sowing, planting, weeding, harrowing, mulching, irrigating, weeding, management of plants (e.g., trellising, controlling pests and diseases) harvesting and the cleaning of harvested produce. The recording of time started when an activity actually began, and ended when the activity actually stopped. The time for breaks from the activities, e.g., when spontaneous conversation with neighbors occurred, was not included in the calculation.

Table 1. *Selbsternte* plots in Austria and their characteristics in 2002.

Location of plots	Province	Year when activity started	Total area (m^2) of subplot[2]	Number of subplots (80 m^2 per subplot)	Plant species sown	Species sown by farmer in addition to those at subplot[3]	Service offered by farmer	Range of fees to be paid for subplots[4] of different size (US$)
Asperhofen	Lower Austria	1998	240	3	22	Spices and medicines	Sowing and irrigation	75/150
Höbersdorf	Lower Austria	1998	1440	18	18	Spices	Sowing	87/140
Mödling[1]	Lower Austria	1998	5120	64	22	Spices and ornamentals	Sowing	100/182
Schwadorf	Lower Austria	2002	480	6	22	None	Sowing	75/140
Tribuswinkel	Lower Austria	2001	2000	25	22	Spices	Sowing and irrigation	90/167
Frauenhofen	Lower Austria	1994	960	12	22	Spices	Sowing and irrigation	125/65
Rothneusiedl	Vienna	1987	32,000	400	23	None	Sowing and irrigation	109/55
Siebenhirten	Vienna	1996	6400	80	19	None	Sowing and irrigation	73/124
Erlaa	Vienna	1995	4800	60	19	None	Sowing and irrigation	73/124
Hirschstetten	Vienna	2000	8000	100	20	Strawberries	Sowing and irrigation	87/145
Hietzing RB[1]	Vienna	1999	1880	24	22	None	Sowing	100/182
Hietzing JPG[1]	Vienna	2000	2800	35	22	None	Sowing	100/182
Alkoven	Upper Austria	1995	800	10	22	None	Sowing and irrigation[5]	100/180
Breitenau	Lower Austria	2000	960	12	22	Spices	Sowing	100/162
Zettling-Graz	Styria	1999	820	12	19	Ornamentals	Sowing and irrigation	100/145/180
Total: 15 plots	4 provinces	–	68,740	861	18–23	–	–	73–182

[1] Plots managed by the Selbsternte company (RB, Roter Berg; JFP, Josef Pommer Gasse, Mödling-St. Gabriel); other plots managed by different organic farmers.
[2] The plot is larger than the total area of subplots, because it includes areas for paths, toolboxes, irrigation facilities and usually also an area with a lawn for recreation.
[3] Some farmers offer an area (between 1 and 10 m^2), where all self-harvesters have access, and where they sow several additional species, such as ornamentals, spices or strawberries.
[4] Fee includes the free use of tools, available at the site, except in Rothneusiedl, where an additional fee has to be paid for the purchase of tools, if not bought somewhere else. Final fee depends of the size of the subplot and the additional services requested by the self-harvesters/offered by the farmers.
[5] Several additional services available upon additional fee (weeding, planting of additional species, etc.).

Table 2. Plants sown or planted by the *Selbsternte* farmer at all subplots [low intensity (LIS) and high intensity (HIS)] and in the HIS subplot at the *Selbsternte* plot Roter Berg,Vienna, with their yields in kg subplot^{-1} (subplot = 80 m^2).

		Yield (kg subplot^{-1})			
		LIS	HIS	HIS	HIS
Scientific name	**English name**	**Species sown by farmer**	**Species sown by farmer**	**Additional individuals**	**Additional species**
Allium cepa var. *cepa*	Onion	3.34	3.14	4.20	x
Allium porrum var. *porrum*	Leek	2.32	2.33	–	x
Apium graveolens var. *rapaceum*	Celeriac	1.95	1.62	–	x
Beta vulgaris ssp. *vulgaris* convar. *cicla* var. *cicla*	Swiss chard	22.07	16.19	3.30	x
Beta vulgaris ssp. *vulgaris* convar *vulgaris* var. *vulgaris*	Beetroot	8.81	4.4	–	x
Brassica oleracea ssp. *oleracea* convar. *caulorapa* var. *gongylodes*	Kohlrabi	1.14	2.11	–	x
Capsicum annuum	Peppers	0.99	0.72	–	x
Cucumis sativus	Cucumber	4.76	2.42	–	x
Cucurbita moschata	Pumpkin	12.66	13.73	–	x
Cucurbita pepo	Zucchini	33.84	31.26	–	x
Daucus carota ssp. *sativus*	Carrots	15.15	14.49	0.42	x
Lactuca sativa var. *capitata*	Iceberg lettuce	0.76	1.22	–	x
Lactuca sativa var. *crispa*	Lettuce	0.74	0.87	–	x
Lycopersicon esculentum var. *esculentum*	Tomato	11.48	9.18	6.91	x
Petroselinum crispum convar. *radicosum*	Parsley root	0.21	2.27	–	x
Petroselinum crispum convar. *crispum*	Parsley	0.1	1.15	–	x
Phaseolus vulgaris ssp. *vulgaris* var. *nanus*	Dwarf bean	8.75	8.88	1.51	x
Pisum sativum ssp. *sativum* convar. *axiphium*	Pea	0.22	0.35	–	x
Raphanus sativus ssp. *sativus*	Radish	0.74	2.02	0.62	x
Solanum tuberosum	Potato	32.99	31.6	–	x
Allium tuberosum	Chinese chive	x	x	x	+
Anethum graveolens var. *hortorum*	Dill	x	x	x	+
Brassica oleracea ssp. *oleracea* convar. *botrytis* var. *italica*	Broccoli	x	x	x	2.29
Cicer arietinum	Chick pea	x	x	x	0.07
Coriandrum sativum	Coriander	x	x	x	+
Cucurbita maxima	Pumpkin	x	x	x	27.52
Eruca sativa ssp. *sativa*	Ruccola	x	x	x	1.45
Glycine max	Soybean	x	x	x	0.43
Ocimum basilicum	Basil	x	x	x	+
Origanum vulgare ssp. *vulgare*	Oregano	x	x	x	+
Physalis peruviana	Cape gooseberry	x	x	x	0.48
Satureja hortensis	Savory	x	x	x	+
Solanum melongena	Egg plant	x	x	x	1.42
Zea mays	Corn	x	x	x	7.01
+ ... herbs					0.68
Subtotal		163.02	149.95	16.96	41.34
Total for LIS and HIS		163.02		208.25	

+, Total quantity of all species with '+' = 0.68 kg subplot^{-1}.
–, No additional individuals sown.
x, Species not sown/not planted.

The rows of plant species were divided into four subsamples of equal length per subplot and all data on harvested produce of those species sown by the farmer were recorded per subsample.

An experimental design based upon randomly distributed replications of low- and high-intensity management was not possible because of the small size of the subplots, the limited number of subplots at Roter Berg and because of the fact that all except two subplots were already reserved by the self-harvesters. Differences in yields of those species sown by the farmer between the two subplots are therefore not analyzed statistically.

After harvest, the produce was cleaned and/or washed and then dried with a rag from washing water at the plot. It was then weighed and the price of the produce for that species was investigated at a randomly chosen organic

produce shop (price for organic produce) and at a randomly chosen supermarket (price for conventional produce) close to the *Selbsternte* plot in Vienna. The yield (kg) was multiplied by the organic and the conventional marked prices of the respective produce and quantity at the selected shops.

Survey of Selbsternte *self-harvesters*

In 2001 28 female and 3 male self-harvesters, and one family, were registered for subplots at Roter Berg (all 32 referred to subsequently as *self-harvesters*). In addition, two subplots were registered for the experiment (total: 34 subplots). Three self-harvesters never did show up and two had to stop their activities during the vegetation period due to health problems. Cultivated species at their subplots developed badly due to the lack of water and the growth of weeds. Produce of their subplots was not harvested. Structured interviews using pre-tested pre-coded questionnaires[15] were conducted with those 27 self-harvesters who worked at their plots at the *Selbsternte* plot Roter Berg until the end of the season.

The self-harvesters were between 30 and 50 years old, married or lived with a partner and had a high school diploma. Half of the users had children. Two-thirds had spent their youth in cities and only one-third in the countryside, but three-quarters reported having helped, at least for a while, in a garden or on a farm at some point in their childhood. Sixty percent of the predecessors of the users had a farm, nursery or a home garden where some vegetables were grown. Eight self-harvesters participated in *Selbsternte* for the first time in 2001, eight for the second time, and nine for the third time. Two of the self-harvesters had more experience than did all the others.

Survey of the Selbsternte *farmers*

Pre-tested interviews with pre-coded and with open questions[15] took place with eight *Selbsternte* farmers in January 2002. Anonymity was guaranteed in the interviews. These *Selbsternte* farmers own between 30 and 140 ha of land. Seven of the farms are managed full time, 1 part time, but all of them are managed by the farmers' families. The size of the *Selbsternte* plots is between 0.02 and 3.3 ha. In addition to the *Selbsternte* activities, farmers keep animals and manage arable crops. Only one farmer grows vegetables in addition to those of the *Selbsternte* plot.

Elicitation of the history of the concept

Semi-structured interviews[15] were conducted with the founder of the Selbsternte company, Mrs R. Bruno, who has worked with the concept since it emerged. These interviews consisted of information on the history of the concept, as well as of her experience with it, and took place between January 1999 and December 2002. To explain the characteristics and history of the concept, the results of these interviews have already been presented in the introduction of this paper.

Results

Survey at the experimental plots

At both subplots, work was done in the *Selbsternte* period (136 days) on 51 days each (2.6 visits per week per subplot). At the LIS subplot 24.2 h (28 min per visit) and at the HIS subplot 38.9 h (46 min per visit) of work were invested on these days. At both subplots the greatest proportion of time was used for irrigation (LIS, 12.2 h; HIS, 17.5 h). More time was dedicated for sowing/planting and soil management (preparing the soil for seeding or planting of additional plants) at the HIS than at the LIS subplot, due to the additional activities realized at the HIS subplot (Table 3, Fig. 4).

Investments were US$184 for the LIS and US$259 for the HIS subplot. The biggest proportion was due to the rental fee for each subplot (US$182). The higher costs of the HIS subplot resulted from the expense of the additionally sown/planted species (US$56) and the necessary additional equipment (US$21; e.g., for posts supporting tomatoes) (Table 3).

The total harvest of fresh produce for the plants sown/planted by the farmers was 163 kg subplot^{-1} from the LIS and 150 kg subplot^{-1} from the HIS subplot. The highest yields of those plants sown/planted by the farmer (mean for LIS and HIS) were achieved with squash (*Cucurbita pepo*; 32.55 kg subplot^{-1}), potatoes (*Solanum tuberosum*, 32.29 kg subplot^{-1}), Swiss chard (*Beta vulgaris* ssp. *vulgaris* convar. *cicla* var. *cicla*, 19.13 kg subplot^{-1}), carrots (*Daucus carota* ssp. *sativus*, 15.03 kg subplot^{-1}), pumpkins (*Cucurbita moschata*, 13.91 kg subplot^{-1}), tomatoes (*Lycopersicon esculentum* var. *esculentum*; 13.78 kg subplot^{-1}) and dwarf beans (*Phaseolus vulgaris* ssp. *vulgaris*

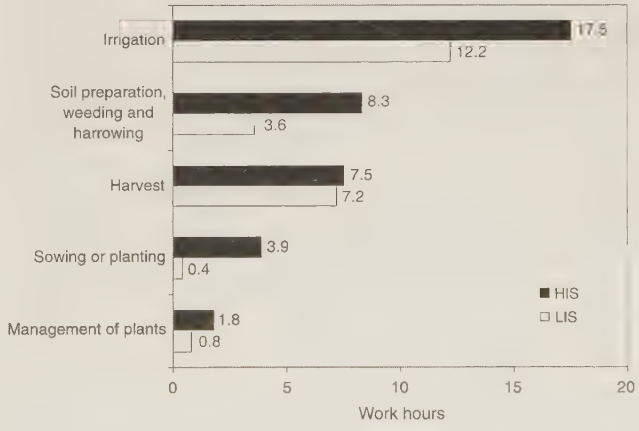

Figure 4. Labor input (total work hours) for the management practices at the low-intensity (LIS) and the high-intensity (HIS) experimental subplots at the *Selbsternte* plot, Roter Berg in Vienna.

Table 3. Results of the survey at the experimental subplots.

Topic	Parameter observed	Unit	LIS	HIS
Species	Number of plant species sown/planted by the *Selbsternte* farmer	Number	20	20
	Number of plant species, where additional individuals were sown at the HIS	Number	0	6
	Number of additional plant species sown/planted at the HIS	Number	0	14
Work	Duration of *Selbsternte* vegetation period	Days	136	136
	Days working at the subplots = number of visits	Number	51	51
	Total work time (see Fig. 4 for details)	Hours	24.2	38.9
	Work time/visit	Minutes	28	46
Cost	Cost: total	US$	184	259
	Cost: details	US$		
	Rental fee		182	182
	Additional seeds/plantlets		2	56
	Tools/equipment		0	21
Yield	Total fresh yield of species sown by farmer	kg subplot^{-1}	163[1]	150[1]
	Total fresh yield of additional individuals and additional species		–	58
	Total yield all individuals and all species		163	208
Value of harvest	Value of produce sown by farmer	US$		
	Conventional prices		219	214
	Organic prices		522	495
	Value of additionally sown/ planted species/individuals	US$		
	Conventional prices		0	150
	Organic prices		0	271
	Value of produce total	US$		
	Conventional prices		219	364
	Organic prices		522	766
Net profit	Net-profit for total harvest (value minus costs)	US$		
	Conventional prices		35	105
	Organic prices		338	507
	Net profit per work hour	US$ h^{-1}		
	Conventional prices		1.5	2.7
	Organic prices		14.0	13.0

LIS, low-intensity subplot; HIS, high-intensity subplot.
[1] Details of yields see Table 2.

var. *nanus*, 8.81 kg subplot^{-1}). Together with the additionally introduced plants, the HIS subplot yielded 208.25 kg of fresh produce (Table 3).

The monetary value of the total of all harvested produce of those plants sown/planted by the *Selbsternte* farmer was US$219 for the LIS subplot, and US$214 for the HIS subplot for conventional prices, and US$522 for the LIS and US$495 for the HIS subplots for organic prices. At the HIS subplot the value of the harvest of the additionally sown/planted produce was US$150 for conventional and US$271 for organic prices. The total value of the harvest at the HIS subplot was US$364 for conventional and US$766 for organic prices. The highest net-profit was achieved at the HIS subplot for organic prices (US$507) and the highest net profit per work hour was achieved at the LIS subplot for organic prices, with US$14 per invested hour of labor (Table 3, Fig. 5).

Survey of the Selbsternte *self-harvesters*

The 27 self-harvesters interviewed live, on average, 1.8 km, or about 10 min, away from the *Selbsternte* plot. Twenty-six self-harvesters bridged the distance on foot or by bicycle. Only one of the self-harvesters traveled exclusively by car. Seven self-harvesters, who usually went on foot or by bicycle, used the car only if they had to transport large quantities of harvested plants.

Of the 27 self-harvesters interviewed, 18 self-harvesters rented subplots of 40 m^2, and 9 rented 80 m^2 subplots. They worked at their subplots, on average, 2.4 times a week. Every visit took them, on average, 1.5 h. Visits reported by the self-harvesters cover the total time of presence at the plot, i.e., work time at their subplots and time for leisure activities at the plot. On average, self-harvesters reported having been at their subplot for 68 h between May 18 and October 31. For half of the respondents, time invested was as they had expected, for one-quarter it was less, and for one-quarter it was more time than expected.

The most frequent activity was irrigating. Seventeen users reported irrigating at least twice a week. The other ten reported less frequent irrigation (between 1 and 6 times a month). Weeding was done by all of them, and more than half (14) weeded between once and three times monthly. The rest did it more frequently. Harrowing

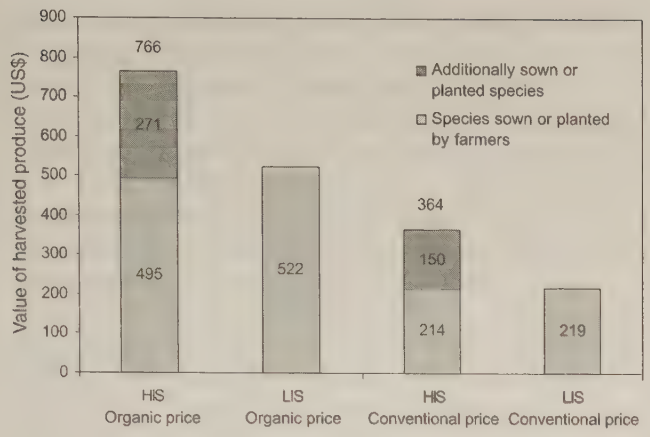

Figure 5. Value of the total fresh harvest calculated according to organic or to conventional prices, in US$, at the both experimental plots (HIS = high-intensity subplot; LIS = low-intensity subplot) at the *Selbsternte* plot, Roter Berg in Vienna.

between rows and in rows between the plants was done by 24 self-harvesters. The majority (17) did this less than three times a month. Harvesting was done at least once a week.

Nine of the self-harvesters believed they invested more cash in the subplot than the value of the harvest yields, and 14 believed they invested less. Twenty self-harvesters harvested all ripe produce; seven left ripe produce at the subplot without harvesting it. Twenty-six also reported having given produce away to friends, relatives, other self-harvesters and passers-by as a gift. Reasons given for leaving ripe produce at the subplot or for giving it away as a gift were the large amount of harvested produce or the dislike of a certain plant species. Neither barter nor commercialization was reported or observed.

All self-harvesters saw the rental of a subplot and the work as an activity of leisure. When asked about what self-harvesters actually did at the plot, 16 self-harvesters reported having done things in addition to their subplot management. These 16 self-harvesters mentioned activities (multiple answers were possible) such as resting and meditating (33%), talking with other self-harvesters (24%), picnicking (12%), playing with children (9%), walking around or nature watching (both 6%), reading a book, sunbathing or taking photographs (all 3%).

Almost all users (24) said they received support in their management of the subplot: the partner, boy- or girlfriend, or husband or wife were the most frequently mentioned helpers (in 15 cases), followed by friends (in 12 cases), children (in 9 cases) and parents (in 5 cases). Several self-harvesters report that several of the persons mentioned helped, but on different occasions. Nineteen self-harvesters got help during their work from other self- harvesters at the plot, mostly from neighbors (12) and the rest from non-neighbors (7). This help concerned mostly irrigation during vacation periods. During the interviews, some cases were reported where border rules were not explained carefully and, consequently, these friends worked at or harvested the wrong subplots. Twenty-six of the self-harvesters reported having invited friends and relatives who were not familiar with the *Selbsternte* concept, to visit the plot.

All self-harvesters reported having visited the subplots of other users. During such visits, the general appearance of the subplots, and specific practices used, were observed and the diversity of plant species was assessed. The observation of differences in yields was reported by only three self-harvesters as something to be assessed during such a visit. Eighteen self-harvesters reported having learned something through talks and observations from these visits, mostly from their neighbors. They learned about weeding, mulching, about the handling of tomatoes, harrowing and about the use of allelopathic effects.

More than half (14) of the self-harvesters reported 'trying something new' at their subplots. The most frequently mentioned innovation for them (multiple answers were possible per person) was growing an unknown species (14 self-harvesters), testing plants as repellents against pests (3), testing effects of mixed cropping, improving the soils with alternative additives (for both, 2), or, e.g., testing different sowing dates, while taking into account the influence of moon, mulch, plant extracts and so on (one self-harvester for all three).

However, there was one clearly visible innovation, first implemented by one self-harvester, that spread through the subplots during the vegetation period and was not mentioned by anybody. This was the use of 1.5 liter plastic bottles for irrigating tomatoes. The bottom of the bottle was cut away, the bottles turned around and stuck (with the bottle neck) into the soil. Water was added to this kind of funnel until it no longer ran from the bottle into the soil, i.e. until the funnel was full of water. The bottle served as a kind of reservoir for 2 or 3 days, releasing the water slowly. While conversing at the plot, consumers who used this kind of irrigation reported advantages such as: direct delivery of water to the roots (i.e., less water dispersed around the plants and therefore less weed growth) and less stress for the self-harvester in getting to the subplots immediately on hot days for the purpose of irrigation.

Twenty-five of the self-harvesters sowed/planted 54 additional plant species or additional individuals of species already sown by the *Selbsternte* farmer. Additional plants were sown where others had been harvested, at the edges of the subplot or between the rows of the already planted species. The most frequently introduced additional individuals of already sown/planted species were iceberg lettuce (*Lactuca sativa* var. *capitata*), dwarf bean (*Phaseolus vulgaris* ssp. *vulgaris* var. *nanu*) and carrot (*Daucus carota* ssp. *sativus*).

The most frequently introduced additional new species were broccoli (*Brassica oleracea* ssp. *oleracea* convar. *botrytis* var. *italica*), basil (*Ocimum basilicum*), ruccola (*Eruca sativa* ssp. *sativa*) and dill (*Anethum graveolens* var. *hortorum*).

Seeds/plantlets of these additional 54 species were distributed by the *Selbsternte* company (61%), shops (12%), friends (8%) and mail delivery companies (6%) or they came from the self-harvesters' own subplots from previous years (8%). In 5% of the cases, the source was not reported. Individual self-harvesters introduced up to 25 new species, but the majority introduced between 6 and 15. Twenty self-harvesters reported having bought only organic seeds/plantlets, while five report having bought organic seeds/plantlets, but also having bought one or the other species from conventional sources.

The most frequently mentioned reasons for sowing/planting additional species ($n = 25$ self-harvesters reported on all additionally sown species) were the preferred taste of a certain species (37%), curiosity (23%), contribution to health (18%), aesthetics (15%), allelopathic effects (4%) and the role in the control of pests and diseases (3%).

Six users related some species to specific events in their youth and nine users related some species to an experience in a foreign country. One of them was German and he reported having introduced chives (*Allium schoenoprasum* ssp. *schoenoprassum*), peppermint (*Mentha* × *piperita*), lemon balm (*Melissa officinalis*), savory (*Satureja hortensis*) and dill. One self-harvester was from Iran and he reported having introduced chick peas (*Cicer arietinum*). Another self-harvester, having been a resident in Japan, reported having sown additional Chinese cabbage (*Brassica rapa* ssp. *pekinensis*), edible crown daisy (*Chrysanthemum coronarium*) and purple shiso (*Perilla frutescens*).

Survey on the Selbsternte *farmers*

All eight farmers reported that the consultancy provided by the Selbsternte company was helpful in establishing their activities. Farmers reported activities such as obtaining technical information, marketing of the concept, organization of meetings and the provision of organic seeds through their license fees as the main benefits of their participation in the Selbsternte company.

Five farmers had contact with the other *Selbsternte* farmers, either at the beginning or later in their *Selbsternte* activities. They reported that exchanging information and exchanging technical equipment were the main reasons for the contact.

Four farmers expected more self-harvesters at the start of their *Selbsternte* activity and all except one farmer want to attract more users in the coming years. When asked what they would do differently if they could begin again, they reported wishing to have made better cost/benefit calculations (2), to have reduced expensive marketing activities (1), to have offered only 80 m^2 subplots instead of a choice of sizes (1) and, because it is too labor intensive, to have done only the sowing, leaving the transplanting of seedlings to the self-harvesters (1). Farmers estimated the value of produce harvested by the self-harvesters as somewhere between 'less than US$100' and 'up to US$500'. None of the farmers could give a figure for the value of the subplot output based upon previous calculations of the same.

The motivating factors in establishing *Selbsternte* plots, as reported by all the farmers, were, primarily, personal (direct contact with self-harvesters, diversification of work to be done, fun), and only then economic.

Only three farmers reported that the income from *Selbsternte* allowed a satisfactory return on the investments made for *Selbsternte*. The contribution of *Selbsternte* varied between 0 and 30% of the total farm income, according to the perception of the farmers. Those farmers who sell their own produce from the farm gate (7) emphasized the fact that *Selbsternte* self-harvesters did actually buy produce at the farm gate or from the farm's own shop and therefore contributed to the income not also with their *Selbsternte* fees but with their weekly spending for produce bought from the farmers.

In total, the farmers sowed or planted 25 plant species. Seeds came from organic seed producers (e.g., the organic seed propagation and retailing company Reinsaat). Plantlets originated from organic seeds and were, depending on the species, bought from organic nurseries or grown at the *Selbsternte* farm by the farmers themselves. Criteria in selecting certain species were personal observations on yields, requests by self-harvesters and recommendations made by the *Selbsternte* consultant. Only one farmer made a cost calculation to determine the rental fee of a subplot. The other seven farmers adjusted their prices to the fees charged by the Selbsternte company for its subplots and according to recommendations of colleagues.

The problems reported with *Selbsternte* are those currently challenging the management of organic farms as well (pressure of weeds, pests and diseases, supply of nutrients). But more frequently farmers reported the following specific technical and social problems.

- The control of EC-Regulation 2092/91, which requests the use of organic seeds/plantlets in subplots, is difficult to manage with self-harvesters who continuously sow seeds/plant plantlets from unidentified sources.
- Self-harvesters who do not weed well may risk weed infestation at other subplots and may be the cause of conflict between self-harvesters.
- Deposition of garbage at the plot by self-harvesters affects the appearance of the plot.
- Low technical skill and self-harvester knowledge of gardening practices (e.g., frequent and long irrigation), which then lead to effects that are a source of complaints (e.g., strong growth of weeds).
- Theft of ripe produce or even of tools in a few cases.

All eight farmers reported that during the course of the vegetation period, many questions from self-harvesters arose and were then addressed directly to the farmers. In many cases, these questions not only covered technical topics matching the farmers' knowledge (time of harvest of certain species, techniques for pest management, etc.), but also related to topics such as processing, storage and cooking. In addition, all of the farmers reported that they

were confronted with problems concerning the social dynamics at the plot (e.g., self-harvester anger about the behavior of neighboring self-harvesters).

As a main success factor, all of the farmers reported the intensity of relations between the self-harvesters and the farmers. At one farm, the farmer gave a subplot for free to an experienced self-harvester, who is present almost every day at the plot and who serves as a kind of representative for the farmer at the plot.

Conclusion

Our results show that self-harvesters who manage a subplot intensively can harvest up to 208 kg of fresh produce, with a value of US$766 from a subplot of 80 m^2. This is above the value expected by the farmers who offer subplots and above the value of US$538 reported from subplots in Witzenhausen, Germany[14]. This result might help farmers to better advertise the concept.

The germination rate and the juvenile growth (not quantified in this survey) of the plants on the experimental subplots, as also seen in some other subplots at Roter Berg, was lower than expected, due to failures in plot preparation by the farmer. Taking into account that other subplots at Roter Berg and subplots at other sites (e.g., Mödling) showed much better developed plants, it is evident that higher yields of harvested produce can be expected with better growing conditions.

Nevertheless, we believe that the importance of the data on yields and value of produce should not be overestimated as, for most species, they come as an excess of produce over a relatively short period of time. Self-harvesters probably would not have spent an equivalent amount of money to purchase the same amount of produce. The lack of sequential plantings, which could avoid the oversupply of produce at a particular time, is a weakness of the system, in which the entire plot is planted at once. Nevertheless, self-harvesters do not see this excess as useless surplus, nor would they sell it. Self-harvesters deal with this excess by organizing dinners with a large number of relatives and friends, by processing produce (pickling, making sauces, drying, etc.) and by giving it away in barter or as a gift.

The better yield performance of the HIS subplot and the value of produce is due to the additionally introduced plants. Introducing new plants is self-harvesters' favorite area of experimentation. Nevertheless, control of the organic origin of seeds and plantlets is a challenge not easily met by farmers.

In managing a *Selbsternte* plot, the farmers involved in the project report the need for close communication with self-harvesters, which not only helps to attract them as clients (marketing), but also provides prior precise and accurate information on necessary technical and social details (e.g., regulations on the 'do's' and 'don'ts'). It is important to provide information that helps to avoid unachievable expectations, secures appropriate social relations between self-harvesters, and—as the plots are certified organic—ensures that substances prohibited in organic farming are not used.

During the course of the vegetation period, many questions arise on the part of self-harvesters. Most farmers have, in our observation, only limited experience and training in the handling of these communication processes. In addition, the huge amount of time necessary for self-harvester relations competes with other activities on the farm. Successful management of *Selbsternte* plots therefore needs a concept of communication, care and training for self-harvesters that would reduce the workload for farmers while ensuring good relations with self-harvesters.

People frequently accompany the authorized self-harvesters (friends, children) but they are not involved in the communication process. These guests might be a risk if they counter the established regulations, and situations such as these can negatively influence relations between neighbors.

The concept of *Selbsternte* needs not only proper social skills but also special technical training for farmers prior to the start of the project. Only one farmer grows vegetables in addition to the *Selbsternte* activities, and no farmer has experience with small-scale horticulture. The participating farmers are growers of arable crops and are used to thinking on a larger scale of agriculture than are self-harvesters, gardeners or horticulturists.

On an arable plot measuring one or more hectares, a failure to sow or germinate, which has an impact on only a few centimeters of a row, might have no real impact for the farmer, if at all. At a *Selbsternte* plot, the lack of a species or of some plant individuals in a certain part of the subplots, resulting from technical errors, leads to adverse social dynamics and can be difficult for the farmer to handle. Therefore, an adaptation of thought, management and of technical equipment to small-scale horticulture is necessary, and farmers must be trained accordingly.

Some species make it necessary to establish a plant nursery in a greenhouse. Some farmers do this for certain species at their farms. The selection of the appropriate species, time of sowing, irrigation, pest management and manipulation of the microclimate in the greenhouse turns out to be a sophisticated task for inexperienced farmers, with possible economic losses for them. Therefore most farmers outsourced the cultivation of plantlets.

Irrigation was carried out whenever self-harvesters believed it was necessary, according to non-professional decision criteria. According to the *Selbsternte* consultants, watering is usually done too often and for too long, resulting, under the usually dry growing conditions around Vienna, in good performance of crops but also intense growth of weeds. This resulted in a high workload for self-harvesters with respect to weeding. Occasionally, and by merit of their agricultural experience, some farmers do the watering with overhead sprinklers in order to raise irrigation efficiency.

The need for the training of farmers, for the exchange of experience between farmers, for accompanying self-

harvester education and for advertising is easier to handle on a common or outsourced level than on an individual level. To secure proper advice when needed, higher fees for subplots and higher license fees were discussed in the Selbsternte company, but were not seen as viable. If this cannot be realized, honorary advisors that are nominated on the basis of experience, and referred to as 'senior' self-harvesters, might be one valuable solution.

The proponents of *Selbsternte* are convinced that this concept leads to ecological, economic and social benefits, which will help to design a sustainable food supply system for small, medium and large cities. Our data allow for the prior formulation of an evidence-based hypothesis on which further testing may be based.

Hypothesis of possible ecological benefits

- The high amount of produce harvested, and the short distance between the residential areas of the self-harvesters and the plot, may help to reduce the duration and frequency of individual tours to shopping malls by car.
- The concept of *Selbsternte* leads to higher agrobiodiversity in the urban area, where this concept is practiced; self-harvesters actively enrich the subplot by seeding/planting additional species. These might be endangered species or cultivars, and therefore the concept might be a valuable element for strategies of *in situ* conservation of agrobiodiversity.
- The produce so harvested does not need packaging and therefore package production and deposition can be reduced for the quantity harvested.

Hypothesis of possible economic benefits

- The monetary value of the vegetables harvested is higher than the money invested by the plot owner. *Selbsternte* plots help to reduce costs for organic nutrition, compared to self-harvester purchases at organic produce shops.
- Local organic gardeners, tool retailers and other providers of necessary and allowable substances benefit from the demand of self-harvesters who have rented *Selbsternte* plots.

Hypothesis of possible social benefits

- *Selbsternte* initiates new networks of communication and collaboration between inhabitants of residential areas, who have not yet met.
- *Selbsternte* plots serve as meeting points for people, allowing for the exchange of opinions, information and knowledge (including that of organic gardening).
- Work at subplots helps participants to relax, meditate and rest after daily business.
- Parents consciously use the work at the subplot to educate their children in horticulture, plant species and related topics.
- Consumers get involved in primary agricultural production. They therefore better understand the risks and challenges that farmers face, as well as the pleasure involved.

Up to now only a few descriptive questions about *Selbsternte* have been addressed. More quantitative data on the ecological, economic and social impact of *Selbsternte* are needed to test these hypotheses. *Selbsternte* subplots can be understood as small experimental stations where self-harvesters merge traditional horticultural techniques with urban ideas on permaculture, sustainable land use and participatory farming. The outcomes of this participatory process of innovation have to be assessed with regard to their potential value for the improvement of urban agriculture, but also for the development of organic farming in general.

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References

1 Bakker, N., Dubbeling, M., Gündel, S., Sabel-Koschella, U., and Zeeuw, H.d. (eds). 2000. Growing Cities, Growing Food – Urban Agriculture on the Policy Agenda. German Foundation for International Development, Feldafing, Germany.

2 Mougeot, L.J.A. 2000. Urban agriculture – definition, presence, potentials and risks. In N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella, and H.d. Zeeuw (eds). Growing Cities, Growing Food. German Foundation for International Development, Feldafing, Germany. p. 1–42.

3 Smit, J., Ratta, A., and Nasr, J. 1996. Urban Agriculture: Food, Jobs and Sustainable Cities. United Nations Development Programme, New York, USA.

4 Moustier, P. 1996. Organisation in the Brazzaville vegetable market. PhD thesis, University of London, UK.

5 Armar-Klemesu, M. 2000. Urban agriculture and food security, nutrition and health. In N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella, and H.d. Zeeuw (eds). Growing Cities, Growing Food. German Foundation for International Development, Feldafing, Germany. p. 99–117.

6 Deelstra, T. and Girardet, H. 2000. Urban agriculture and sustainable cities. In N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella, and H.d. Zeeuw (eds). Growing Cities, Growing Food. German Foundation for International Development, Feldafing, Germany. p. 43–65.

7 Grünsteidel, I. 2000. Community Gardens – Grüne Oasen in den Ghettos von New York. In E. Meyer-Renschhausen and A. Holl (eds). Die Wiederkehr der Gärten. Studienverlag, Innsbruck, Austria. p. 125–139.

8 Gröning, G. 2000. Kampfesmutige Laubenpieper – Kleingärten und Politk in Berlin zwischen 1985 und 1995. In E. Meyer-Renschhausen and A. Holl (eds). Die Wiederkehr der Gärten. Studienverlag, Innsbruck, Austria. p. 140–161.

9 Akemine, T. and Pestemer, R. 2002. Die Selbstversorgungs-Guerilla in Japan. In E. Meyer-Renschhausen, R. Müller, and P. Becker (eds). Die Gärten der Frauen – Zur sozialen Bedeutung von Kleinstlandwirtschaft in Stadt und Land weltweit. Centaurus, Herbolzheim, Germany. p. 178–188.

10 Garnett, T. 2000. Urban agriculture in London: rethinking our food economy. In N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella, and H.d. Zeeuw (eds). Growing Cities, Growing Food. German Foundation for International Development, Feldafing, Germany. p. 477–500.

11 Galanti, G. 2002. Integrating ecological practices into urban garden management in developing countries. Urban Agriculture Magazine 6:15–16.

12 Van Hirtum, M., Goewie, E., Getachew, Y., and Van Veenhuizen, R. 2002. Transition to ecological urban agriculture – a challenge. Urban Agriculture Magazine 6:1–3.

13 Böhnhardt, J., Fennekohl, K., Engelhardt, H., Winnicki, T., and Hess, J. 1999. Gemüse selbst ernten. University of Kassel, Kassel-Witzenhausen, Germany.

14 Wortmann, A. 2000. Gemüse selbst ernten auf der Domäne Frankenhausen: Ein Beitrag zum nachhaltigen Konsum. Masters thesis, University of Kassel, Kassel-Witzenhausen, Germany.

15 Bernard, H.R. 2002. Research Methods in Anthropology – Qualitative and Quantitative Approaches. Altamira Press, Walnut Creek, California, USA.

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Building a farmer-centered land grant university organic agriculture program: A Midwestern partnership

Kathleen Delate[1,*] and Jerald DeWitt[2]

[1]Departments of Agronomy and Horticulture, and [2]Department of Entomology, Iowa State University, Ames, Iowa 50011, USA.
*Corresponding author: kdelate@iastate.edu

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Abstract

Based on citizen demand, Iowa State University (ISU) established the first organic specialist faculty position at a US land grant university in 1997, as a shared appointment in the departments of horticulture and agronomy, with a 70% extension and 30% research split. By 1999, a national survey determined that ISU had reached the upper percentile of organic research, extension and educational activities at land grant universities in the US. This result was attributed to a series of successful Organic Agriculture Focus Groups in 1998, convened to help direct the new organic research and extension program at ISU. Partnerships with the Leopold Center for Sustainable Agriculture and the College of Agriculture facilitated the ISU sustainable agriculture extension leader and organic specialist's participation in an extensive focus group dialogue with a diverse group of farmers (organic and conventional), agribusiness professionals, bankers and consumers in six agricultural communities across Iowa. Focus group responses included the need for organic research at the university level, since the majority of organic farmers (65%) were receiving their information from other organic farmers and non-governmental publications. Paramount in the needs assessment was the establishment of organic research sites across the state to demonstrate the economic and environmental benefits associated with organic farming practices over the long term. Specific outcomes-based extension needs were articulated, which led to the development of an annual schedule of organic workshops, field days and conferences. In 2001, in a survey of 300 farmers to assess the outcomes of the Organic Agriculture Program, all respondents (39% return rate) reported benefiting from an extension organic program. Similar to focus group results, farmers rated workshops and field days as the most likely venue for information dissemination. As a result of organic farming practices, 90% of respondents reported an increase in soil quality and 67% reported a 6–30% increase in farm income. The success of land grant university organic programs will be dependent upon administrative support, sufficient resources and community involvement in the decision-making process.

Key words: extension, focus groups, long-term research, outcomes-based, producer-driven, surveys

Introduction and Background

The demand for lower pesticide residues in food and in the environment has led 90% of US citizens to consider including organic foods in their diets[1]. US organic acreage has increased from 607,500 ha in 1995 to 931,500 in 2001, with annual organic sales exceeding 20%[2]. Based on the increase to 8100 ha of organic production in Iowa in 1996[3], a diverse group of producer and industry citizens approached Iowa State University (ISU) College of Agriculture administrators to request the establishment of an organic program at ISU to help Iowa producers meet the increasing demand for organic products. The group consisted of extension staff, agricultural professionals, organic farmers and conventional farmers interested in transitioning to organic agriculture. These citizens recognized that, despite the growth in organic agriculture across the US, research and extension activities in organic farming systems were limited, particularly at land grant universities.

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The Organic Farming Research Foundation (OFRF) had determined that less than 0.1% of US Department of Agriculture research addressed organic farming systems in 1999[4]. Much of this omission derived from the complexity of questions arising from organic farming systems research[5,6], and the limited knowledge of the mechanisms operating in organic farming systems[7]. In another survey conducted in 1999, 'extension' was cited as one of the critical impediments to adoption of organic practices[8], due to limited organic agriculture educational opportunities for extension and research faculty prior to 1997. Subsequently, farmers were driven to develop solutions to research problems within their own farmer groups, without the assistance of their local extension specialists[9].

Iowa State University sought to address this gap by hiring an organic specialist in 1997 to serve on the College of Agriculture faculty. It was decided that the position would reside in the departments of horticulture (70%) and agronomy (30%), in order to serve organic grain, vegetable and fruit growers in the state. The job description for the position was developed with community involvement, including local farmers and Department of Agriculture and Land Stewardship (IDALS) Organic Program staff. Subject matter expertise required in the position included the aforementioned crops, in addition to herbs, turf and agroforestry systems, as a 70% extension and 30% research appointment. Some of the benefits and drawbacks of this broad, multidisciplinary job description will be discussed in this paper. Recruitment for the organic specialist position included advertisements in agricultural professional society journals and other venues. Included in the interview process were members of the original group who had approached administrators on the need for this position, the faculty search committee, and members of IDALS and Practical Farmers of Iowa. Community members queried the candidates regarding their experience with organic systems and on-farm research, which they viewed as important criteria for success in the position.

Once the organic specialist was selected, a Sustainable Agriculture (SA) Summit was held on June 30, 1997, to acquaint the new specialist with faculty members and Iowa farmers working in sustainable and organic agriculture. Sponsored by the USDA-SARE (Sustainable Agriculture Research and Education) program, this day-long workshop, organized by the SA extension coordinator at ISU, served as the initial venue for reviewing the research and educational needs of organic producers.

Organic Agriculture Focus Groups

Also participating at the SA Summit was the Leopold Center for Sustainable Agriculture (LCSA), a public institution housed at Iowa State University to provide support for research and educational activities that increase the viability of Iowa agriculture through more environmentally sound and community-based practices. Early in the appointment of the organic specialist, the LCSA offered financial and logistical support to the Organic Agriculture Program. Based on concepts described by Chambers et al. (1989)[10], the LCSA recognized farmers as central to the research process, and encouraged the organic specialist to establish a research agenda based on organic and transitioning farmer-identified problems. Extending research results throughout the state's farming communities was also a goal of this new program.

In February 1998, a series of Focus Groups was organized by the organic specialist and the ISU SA extension leader (J. DeWitt). Using lists of active extension participants from state extension staff (Table 1), 60 organic and conventional farmers (crop, livestock and vegetable producers), agribusiness professionals, bankers and consumers received personal invitations to participate in the development of the organic research and extension agenda for Iowa State University. Focus Group meetings were held in conjunction with a locally produced supper in six diverse communities across Iowa. A set of ten questions related to participants' perception of support for organic producers at ISU and their research needs was distributed in the letter of invitation to community members (Table 2). Each Focus Group differed in their specific responses, depending on their operations (agronomic versus horticultural).

The Focus Group meetings began with several general questions regarding knowledge of the associations in Iowa working with organic farmers, including the Leopold Center for Sustainable Agriculture, the Iowa Department of Agriculture and Land Stewardship, and Practical Farmers of Iowa. When queried on personal knowledge of the new (7-month-old) organic agriculture program at Iowa State University, 67% expressed some familiarity with the program. The majority of participants (52%) perceived a positive future for organic agriculture in Iowa, with the greatest optimism (86% positive) from the areas of highest organic farming concentration (northeast and southwest Iowa). Several areas of interest were presented by participants:

- 'Vegetables could be a new area for Iowa's organic producers, but volume is the key. We need to develop needed infrastructure, such as processing centers.'
- 'Farmers are very interested in doing more organic research.'
- 'The organic movement will continue to grow quickly, with opportunities for small scale, family producers, especially organic fruit.'
- 'There is a good potential for organic herb production in Iowa.'
- 'Organic meat opportunities exist, but will take time.' (This has since changed, with the passage of labeling for certified organic meat in 2000.)
- 'Conventional farmers need help to become more knowledgeable about organics.'
- 'My organic crops are going great and there is a need for more organic grains.'

Table 1. Focus Group participant attributes.

Focus Group community location and principal farming operations	Participant profession (total number over six groups)
Group 1: Southeast Iowa, agronomic/livestock	Organic producer (15)
Group 2: Northwest Iowa, agronomic/livestock/horticultural	Conventional producer (19)
Group 3: Southeast Iowa, vegetables	ISU extension, agronomy (4)
Group 4: Northeast Iowa, agronomic/livestock	ISU extension, horticulture (2)
Group 5: Southwest Iowa, agronomic/livestock	ISU extension, communities (2)
Group 6: Central Iowa, agronomic	ISU farm manager (4)
	Grain cooperative manager (2)
	Community ag. marketer (1)
	Crop consultant (2)
	Banker (1)
	NRCS (1)
	Livestock feed operator (1)
	Other ag./environmental business (6)

ag, agricultural; NRCS, Natural Resources Conservation Service

Table 2. Organic Agriculture Focus Group questions.

1. Prior to receiving this letter and coming to this meeting, were you aware that Iowa State University has a full-time faculty member working in organic agriculture?
2. Are you aware of the Leopold Center for Sustainable Agriculture and its conferences?
3. Are you aware of the IDALS Organic Agriculture Program? Practical Farmers of Iowa?
4. What do you see as the future for organic agriculture in Iowa, related to:
    - Field crops?
    - Horticultural Crops?
    - Livestock?
5. What is your feeling on how much work in organics ISU has undertaken to date?
6. How much effort (faculty positions, research, extension efforts) *should* ISU spend in organic or transition (to organic) research, teaching and extension?
7. If ISU embarked on organic research, how much effort should be devoted to:
    - Organic field crops?
    - Organic horticultural crops?
    - Organic livestock?
8. If you are an organic farmer, or you know organic farmers, what are the main sources of information for organics?
9. What do you think is the most effective method for reaching organic farmers (or those interested in organics):
    - Extension workshops/conferences?
    - Publications?
    - Newsletters?
    - Other methods?
10. What specific research in organics would you like to see at ISU?

- 'There is a high demand for organic, food quality, tofu soybeans.'
- 'I am cautious, because, currently, the driving force is organic soybeans. I'm afraid that this will not be the big picture down the road.'
- 'Organic provides an opportunity for farmers to ''size-down''. Because it is more labor intensive, I am concerned about the larger organic operations, who may not realize labor demands.'
- 'People want to see more ''Iowa grown'' products.'
- 'Profitability will be key for most producers.'

In response to the question on availability of existing organic research, only 39% of respondents considered organic research activities at ISU to be adequate at that time. Half of the Focus Groups requested that '100% more effort be given' with the average response requesting '93% more effort'. Because Iowa is primarily an agronomic state, 42% felt that the majority of organic research should be in agronomic crops, followed by livestock, composting and horticultural crops. Most organic farmers (65%) were receiving their information from other organic farmers and non-governmental publications because of the lack of university-based information on organic farming in 1998. When queried on the preferred method of information dissemination, 45% felt that intensive workshops were more effective than publications or field days.

Research needs

An open discussion among Focus Group participants identified the need for increased research on transition strategies for organic production, including crop rotations for specific Iowa conditions. Other research requests included crop (horticultural and agronomic) variety trials under organic management, and pest management strategies for organic vegetable production. A prevailing theme articulated by producers and agricultural professionals at the Focus Groups was the need for a long-term evaluation of organic agriculture systems. As a result of this request, Long-Term Agroecological Research (LTAR) sites were established in 1998 in four areas of Iowa[11] to examine the short- and long-term physical, biological and socio-economic effects of organic and conventional farming systems. Altieri (1995)[12] defined 'agroecology' as the science of agroecosystems, including the physical, biological and cultural features (socio-economic) operating within and upon the agricultural system. All aspects of soil quality and pest status, as affected by the farming system, are included in the agroecological analysis. Feedback from the local farm associations that are responsible for farm stewardship and farm finances at the LTAR sites was considered an integral part of the LTAR process[11].

By establishing long-term experimental sites in four distinct agroecological zones in Iowa, researchers could test the hypothesis that longer crop rotations, typical of organic farms, would provide yield stability, improve plant protection, and enhance soil health and economic benefits compared to conventional systems with shorter rotations and greater off-farm, synthetic inputs. Spatial and temporal variation in physical, chemical and biological soil constituents are quantified in all LTAR sites to identify changes in soil quality, a key component of sustainable farming systems[13]. Because organic farmers undergo organic certification to obtain premium prices, adherence to certified organic practices and third-party certification of all organic research fields are important components of these projects. Supporting factors for long-term research, identified at the Focus Group meetings, included the recognition that, because most farmers begin their transition into organic production from conventional fields, a minimum of 3 years of research was needed, as required for organic transition[14]. In addition, organic farmers reported improvements in soil quality and plant productivity after several years of organic management, and only longer research trials could elucidate this effect. By involving local farmers in the planning process, experimental design, sampling protocols and review of research results in the long-term experiments, we sought to obtain outcomes that would benefit the entire community.

Financial support for these long-term sites was secured through grants written by the organic specialist, with cooperators located in research and extension faculties from ten Iowa State University departments, a local farm association, and the Adair County Extension office (Table 3). The Leopold Center for Sustainable Agriculture provided the initial investment in the organic research program, funding a full-time technician to support the organic specialist. Grants were also secured from the USDA-North Central Region Sustainable Agriculture Research and Education Program (SARE), and the USDA-IFAFS (Initiative for Future Agricultural and Food Systems) program, in the third and fourth year of the program, respectively. The interdisciplinary nature of the LTAR program is reflected in the diverse disciplines of the ISU staff working at the site, Heartland Organic Marketing Cooperative and four organic seed companies who provide materials and marketing support.

Extension needs

Specific extension needs were also assessed in Focus Group discussions. An outcomes-based plan was developed to address these needs, based on producer requests for a combination of publications, intensive workshops and field days. Publications have been developed into an Organic Agriculture series through the Iowa State University Extension Communications office, and an Organic Gateway webpage was initiated (Table 4). An annual series of organic workshops and field days are also held (Table 5). The demand for information was unparalleled in this program. Over the course of 3 years (1997–2000), the organic specialist presented 140 invited talks on organic agriculture to an audience of 6000 producers, agricultural professionals and consumers. Field days attracted 1150 participants, ranging from organic and conventional farmers to extension specialists and students.

Outcomes driving this research and extension program include:

- number of increased hectares in organic production;
- decrease in nitrate pollution from use of slower-released nitrogen in organic systems;
- increase in soil quality from soil amendments, including crop rotations and compost;
- decrease in pesticides from reliance on natural control (biological, cultural and physical controls); and
- increase in family farm income as a result of adopting organic practices.

Education needs

The Focus Groups also requested that an organic agriculture academic program be developed at Iowa State University. The first organic course at ISU, Organic Crop Production, was developed as a joint agronomy and horticulture undergraduate class in spring semester of 2000 and offered to 168 students [43 on campus, 125 attending via the Iowa Communication Network (ICN)] from ten remote sites throughout the state (see Appendix 1). Evaluations from course participants included an appreciation for knowledge gained and requests for additional courses. In addition to undergraduate activities,

Table 3. Interdisciplinary team in the Iowa State University Organic Agriculture Program.

Cooperator title (number of individuals)	Professional home	Role
Assistant professor (1)	Iowa State University Department of Horticulture and Agronomy	Coordinate Organic Agriculture Program; provide leadership on organic production aspects of project
Advisory committee (15)	Farmers, marketers, consumers	Provide input on research needs, design and evaluation; provide expertise at trainings/conferences
Extension (field staff): community specialist (1), agronomist (1), farm management specialist (1)	Three county offices	Provide input on community involvement and area of expertise in organic projects
Professors (2)	Department of Entomology (with biological control and sustainable agriculture responsibilities)	Provide leadership on entomological aspects of project and assist in coordination of extension activities
Associate professors (6)	Department of Agronomy (with responsibilities in soils, small grains, weeds and forages)	Provide leadership on crop and soil aspects of organic projects
Research scientists (2)	USDA-ARS National Soil Tilth Laboratory	Provide leadership on soil biology aspects of organic projects
Assistant professor (1)	Department of Agriculture and Biosystems Engineering	Provide leadership on composting aspects of organic projects
Associate professors (2) and professor (1)	Department of Plant Pathology	Provide leadership on plant pathology and nematology aspects of organic projects
Professor (1)	Department of Anthropology and Sociology	Provide leadership on sociological aspects of organic projects
Professor (1)	Department of Economics	Provide leadership on economical analysis of organic projects
Extension coordinator (1)	Practical Farmers of Iowa, Department of Agronomy	Provide leadership on Field Day and farmer-cooperator aspects of organic projects
Professor (1)	Department of Food Science	Provide leadership on food science aspects of organic projects

Table 4. Organic agriculture publications through Iowa State University Extension.

Publication title	Authors
Organic Agriculture	Organic specialist
Soil Quality in Organic Agriculture	Organic specialist, USDA-ARS soil scientists
Integrated Weed Management in Organic Agriculture	Organic specialist, ISU weed specialist
Growing Organic Soybeans on CRP Land	Organic specialist

four graduate students have matriculated in the organic program in 4 years (3 M.S. degrees; 1 M.Ag.), with degrees in horticulture, agronomy or agricultural education. Research theses in the graduate program have included organic apple pest management, food quality of organic and conventional crops, alley-cropping in agroforestry systems, and weed management in organic medicinal herb production. Because undergraduate student education is also key in influencing future leaders in organic agriculture, an average of six undergraduate students have worked as research assistants in the organic program each year since 1997. Ten student interns from the US and abroad have also played a significant role in research and extension activities in the organic program from 1997 to 2001 (Table 6).

Comparison of the ISU Organic Program: An Overview of US Land Grant University Organic Activities

Eighteen months into the organic program, at the request of the OFRF, we composed a questionnaire for a national survey of land grant universities' activities in organic agriculture. These results were presented at a workshop at the American Society of Agronomy annual conference in Salt Lake City, Utah, on November 2, 1999. The goal of

Table 5. Extension activities in organic agriculture at Iowa State University.

Extension event	Description	Frequency of offering
Organic research field days	In-field reporting of research results for farmers, NRCS, extension, local agricultural business, students	Annually: five research sites per year
Organic on-farm trials field days	In-field reporting of research results with farmer-cooperator for farmers, NRCS, extension, students	Annually:one farm per year (average)
Organic Weed Management Workshop	Intensive day-long workshop demonstrating in-field practices for farmers, NRCS, extension	Annually: rotating to different research farms every year
Organic Fruit Production Workshop	Workshop with farmer-cooperators on principles and practices of organic fruit management	Annually: at research farm or on-farm site
Organic Conference	Day-long conference on organic certification, crop production and marketing	Annually (winter)
'Toolbox Training for Organic Agriculture' Workshop	Intensive workshop with farmer-cooperators on principles, practices and legalities of certified organic production	Annually (summer)

this survey was to identify trends in organic agricultural research, extension and education at land grant universities and establish a network of scientists working in organic agriculture. A concomitant goal was to identify unmet organic research needs based on the OFRF producer survey[8]. Land grant university survey results were intended for dissemination to agricultural administrators and funding agencies whose mission included assistance to organic and conventional farmers.

Beginning in 1988, when the USDA-SARE program provided funding to enable land grant universities to implement extension training in sustainable agriculture, each land grant university identified a coordinator to administer these funds and develop sustainable agriculture programs. Our questionnaires were mailed to these SARE-funded sustainable agriculture coordinators at 50 land grant university programs in August 1998. We targeted these coordinators because they were acknowledged leaders in sustainable agriculture at their universities, and it was presumed they would be cognizant of organic agriculture activities as part of their sustainable agriculture duties.

Organic activities at land grant universities survey results

By March 30, 2000, 23 responses (66% return rate) were tabulated. According to the sustainable agriculture coordinators surveyed at land grant universities, organic agriculture activities had progressed rapidly in the past decade, but additional support was critical for full implementation of producers' requests. Off-campus extension personnel were cited as the main educators in organic agriculture, rather than campus faculty. Fifty-four percent of the respondents identified 1–4 extension staff offering organic extension activities (workshops, meetings and field days). Of the remaining sites, there were limited extension activities. One university reported that 'beyond a handful of local Extension educators', organic agriculture activities were practically nonexistent at their institution. Thirty-four percent of respondents had not developed any extension brochures on organic agriculture. Twenty-nine percent reported publishing 1–3 organic brochures, and one university listed 12 organic agriculture brochures, although half of these related to components (e.g., composting,

Table 6. Internships in the organic agriculture program at Iowa State University.

Year	Type of internship	Number of students involved	Gender	Country or state
1999	Women in Science and Engineering	1	F	Iowa
1999	Agriculture Minority Program	1	M	Hawaii
2000	International Agriculture Program	3	F (3)	Spain, Mexico, France
2001	Agriculture Minority Program	2	F	Missouri, California
2001	International Agriculture Program	2	M (2)	Spain, Brazil
2002	International Agriculture Program	1	M	Spain

biological control) that could be used on organic or conventional farms.

Confusion over the term 'organic', however, may have skewed some responses in favor of organic activity. Several coordinators did not distinguish 'organic' from 'integrated pest management' or 'sustainable agriculture'. 'Our research is *close* to organic farming, using a minimal amount of inorganic fertilizer and pesticides,' a respondent from a western state wrote. Because synthetic fertilizers and pesticides are prohibited in organic farming, however, even 'a minimal amount' of these products would not constitute organic agriculture research. It is important to note that research in 'sustainable agriculture' and 'integrated pest management' may provide potential application in organic farming, but only dedicated organic farming research will provide specific answers for organic farmers[4].

There were also some uncertainties expressed regarding which faculty members were working in organic agriculture at their university. A sustainable agriculture coordinator for a northwestern land grant university wrote: 'There is no central database for this kind of information'. Despite this purported lack of networking among scientists working in organic agriculture, 45% of the respondents reported having 1–4 faculty working on organic research activities at their university. Six universities listed organic research and demonstration farms. Personal notes, including initial organic agricultural research results, were added, such as, 'Our organic corn did great this year in spite of the drought'.

The importance of conducting organic research using certified organic practices cannot be overstated[9]. Conducting research on certified organic farms expedites this process, in addition to facilitating community involvement and clientele support. While 39% of the respondents identified 1 to 4 on-farm university trials on organic farms, 24% had not involved organic farmers in their research. Educational activities in organic agriculture at land grant universities were lagging behind extension efforts. Thirty-two percent of surveyed universities offered 1–3 courses in organic agriculture, although some of these 'courses' constituted a section of a larger course, in the areas described above. No courses on organic agriculture were offered at 45% of the responding land grant universities.

Constraints to organic agricultural activities that were cited by respondents included lack of administrative support and resources (funding, personnel and time). 'Change to date has not been dramatic, but gradual, steady', was a typical trend reported in the surveys. Fifty-seven percent of the respondents received administrative support for organic agriculture activities, while 37% received minimal support from their administration. An equal number (57%) received support from their home departments. A number of faculty reported an interest in organic agriculture, but their 'over-commitment in current position responsibilities which do not include organic agriculture' has restricted their activities in organics. Three respondents wrote of great interest expressed in their colleges, but that 'limited financial resources had been directed toward organic research, Extension and education activities at the college level'. Some of the larger commitments to organic research (US$250,000 at one Midwestern land grant university) were single appropriations with uncertain long-term assurances. Two universities mentioned US-EPA grants as sources of funding for organic extension activities. Additional problems with continued commitment toward long-term organic activities included 'failure to follow-up' on initial organic activities. Sixty-one percent of respondents reported that efforts in organics would increase at their institution in the next 5 years. Thirty-six percent, however, expressed doubt over any increase in efforts. Of the respondents who predicted increased efforts, many ascribed this effect to increased farmer demand.

Organic research programs identified in the surveys focused on methods to improve organic farming systems. Because organic farmers rely on crop rotations, compost or manure applications, and/or cover crops to satisfy crop nutrient requirements[15], much of the organic agriculture research efforts focused on nutrient management. This interest corresponds with that expressed by organic farmers in a national survey[8], where pest management and soil fertility were the most critical management problems for organic growers. Employing the goal of a sustainable, organic farm by replacing external inputs with on-farm or locally produced inputs, many producers are constrained by the lack of adequate inputs (e.g., manure, compost or cover crop biomass) to provide sufficient nutrients for optimal yields. Thus, several research programs are examining the effect of crop rotations and organic amendment combinations on crop performance and soil health. Fewer organic agricultural programs were involved in an analysis of the underlying mechanisms operating in organic farming systems, as described by Niggli and Lockeretz (1996)[16]. Long-term agroecological, systems research requires resource commitments that few land grant universities have made at this time.

ISU Organic Agriculture Program Evaluation

In November 2001, 300 questionnaires were mailed to Iowa farmers and other agricultural professionals to assess the value of the ISU Organic Program after 4 years of operation (1997–2001). At this time, Iowa was listed as both a leader in organic production and number of organic operators in a national survey[2]. Program evaluation survey results were anonymous and coded by independent assistants. After allowing 6 months for returned surveys, a summary was developed in May 2002, from 116 surveys, representing a return rate of 39%. Trends that were observed from survey results (see Appendix 2) included a high return rate from organic family farmers, farming 120–300 acres, of primarily corn, soybean and oat crops. Twenty-one percent of respondents reported organic fruit, vegetable, herb and

tree crop production. These results corresponded with Focus Group responses from 1998, where the majority of farmers expressing interest in ISU's Organic Program produced agronomic crops. The majority of respondents had been farming organically for 3–6 years, which mirrors the organic industry growth of 18% from 1994 to 2000 in Iowa[17]. Respondents reported using a variety of marketing outlets, with primary markets listed as wholesale cooperatives or brokers (25% average). A growing number were direct marketing through Community Supported Agriculture (CSA) operations (5%), farmers' markets (4%), on-farm sales (10%), and direct sales to retail outlets and consumers (24%).

When queried on methods for maintaining soil fertility and soil quality, farmers reported using a diversified, systems approach, with 85% reporting a mixture of crop rotations with leguminous crops, manure and compost applications. These results correspond with those of earlier reports[15,18], where animal-based and cover-crop-based fertilization have been effective for increasing soil organic matter and biological activity within organic production systems. In following the organic agricultural principles of recycling local inputs, only 15% of respondents reported off-farm purchases of soil amendments. Because the majority of Iowa organic farmers raise livestock on their farms, on-farm sources of manure and compost tend to be more available in Iowa than in many other states, such as California (B. Leahy, personal communication, 2003). Soil amendments and crop rotations have been shown to increase soil organic matter and improve water-holding capacity. Thus, survey results attempting to quantify environmental effects from organic practices in Iowa (see Appendix 2) were generally positive with regard to soil enhancement: positive changes in soil quality were reported by 90% of respondents, including decreases in soil erosion (71% of respondents reported observing the decrease) and improvement in water-holding capacity (86% of respondents). The average reported reduction in erosion was 41%, measured against erosion observed on farms prior to initiation of organic practices.

Other beneficial effects included enhancement of the following indicators: earthworm populations (49% increase), crop performance (31% improvement), crop health (28% improvement) and beneficial insects (40% increase). Pest insects were, on the average, 33% of population levels during conventional farming periods. A full 55% of respondents reported observing a reduction in nitrates leaching from their farms. Unlike other categories, where a limited number of deleterious effects were reported from organic agriculture practices, there were no reported increases in nitrate contamination from organic agricultural practices on any survey. Similar beneficial environmental effects have been reported on organic farms in California[19–21]. Of particular importance to farmers in the survey was the relationship of organic practices to farm income, with 67% reporting a 6–30% increase from the adoption of organic practices.

In reviewing the applicability of the ISU Organic Program to organic farmers, all respondents had participated in at least one extension program, with the majority attending field days (31%), conferences (23%) and workshops (20%). Twenty-one percent of respondents reported a direct exchange of information via telephone, e-mail or personal contact with staff in the ISU Organic Program. Participation at conferences and workshops was preferred over reading extension publications (11% reported reading at least one of the organic publications), although, at the time of the survey, the Organic Agriculture series of extension publications had been available for only a short period of 6 months. Nine percent of respondents reported attending the ICN Organic Agriculture course, which may have included some of the 125 farmer-students enrolled in the course. When respondents were asked to select best methods of communication from ISU staff, 'personal visits without compensation to ISU' was rated as the most important method. However, when queried on willingness to pay for services, the majority of respondents (49%) stated that they would pay a nominal fee, and another 20% would cover full program costs. In this era of cost-recovery, the fact that 69% of respondents would be willing to support the program through nominal or full costs for services suggests a perceived high value for these services.

Discussion

The growth in organic production is expected to continue, as more farmers struggling with current low commodity prices become interested in organic farming. Consistent federal standards for products marketed as 'organic' in the US will allow the industry to pursue other growth opportunities[22]. New government support for organic research and education activities is the result of increased organic demand across the US[23]. Research results from land grant universities suggest that organic cropping systems are economically viable, particularly when producers receive certified organic premiums[11,24], and could be even greater if credit were applied to agricultural operations that accrue benefits to society as a whole[25]. Governmental support for organic agriculture in the European Union has exceeded US support[26], but with the implementation of the 2002 Farm Bill, opportunities for organic farming research and cost-sharing activities are scheduled to increase[2].

Land grant universities are expected to respond to this growing demand through the development of organic agriculture research, education and extension programs at their institutions. The Organic Agriculture Program at Iowa State University ranked in the top 10% of extent of organic activities at land grant universities in 1999, and was listed as one of three land grant universities with certified organic research lands[9]. Inherent in the success of the ISU organic program is administrative support, sufficient resources and community involvement in the decision-making process. In order to develop policies to enable establishment of

alternative agricultural enterprises, an ongoing assessment of farmers' needs and constraints will be required[27].

Constraints affecting further adoption of organic agricultural practices include the need for additional staff in the organic agriculture program at Iowa State University to meet the increasing demands for research and educational information in all sectors of organic agriculture (agronomic crops, horticultural crops, livestock and marketing). Grant-writing for funding from extramural sources, including private industry and governmental agencies, has required 20% of available time. Newly formed organizations, including the Scientific Congress of Organic Agriculture Research (SCOAR), sponsored by the Organic Farming Research Foundation[28], will assist understaffed land grant university scientists by serving as sounding boards for organic farmer research and education needs. The ultimate goal of this network of agricultural scientists currently involved in organic agriculture research and extension is to improve the viability of agriculture through the development of sustainable practices by involving local producers and consumers in the process. A promising development on the federal front is the recently articulated 'Vision for Agricultural Research', which acknowledges the role of the environment and communities among its goals[29]. This increase in environmental and community awareness in agriculture suggests an expanded role for researchers and extensionists, with a focus on organic agriculture at land grant universities.

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References

1 Hartman Group. 2001. Natural Sensibility, Typification of the New Wellness Consumer, Vol. 3(2). Hartman Group, Bellevue, WA.
2 Greene, C. and Kremen, A. 2002. US Organic Farming: A decade of expansion. In Agricultural Outlook (November). USDA-Economic Research Service, Washington, DC. p. 31–34.
3 Iowa Department of Agriculture and Land Stewardship (IDALS). 1997. Annual Survey on Organic Production. Iowa Department of Agriculture and Land Stewardship Diversification Bureau, Des Moines, IA.
4 Lipson, M. 1999. Looking for the 'O' Word. Organic Farming Research Foundation, Santa Cruz, CA.
5 Norgaard, R.B. and Sikor, T.O. 1995. The methodology and practice of agroecology. In M. Altieri (ed.). Agroecology. Westview Press, Boulder, CO. p. 21–40.
6 Vogtmann, H. 1990. Research structure in biological farming: general view, justification, development. In Biological Farming in Europe. REUR Technical Series, 12. Proceedings of the Expert Consultation. FAO, Bern, Switzerland. p. 41–47.
7 Høgh-Jensen, H. 1998. Systems theory as a scientific approach towards organic farming. Biological Agriculture and Horticulture 16:37–52.
8 Walz, E. 1999. Final Results of the Third Biennial National Organic Farming Survey. Organic Farming Research Foundation, Santa Cruz, CA.
9 Sooby, J. 2001. State of the States. Organic Farming Research Foundation (OFRF) Bulletin 6. OFRF, Santa Cruz, CA. p. 14–16.
10 Chambers, R., Pacey, A., and Thrupp, L.A. 1989. Farmer First: Farmer Innovation and Agricultural Research. Intermediate Technology Publications. Bootstrap Press, New York.
11 Delate, K. 2002. Using an agroecological approach in farming systems research. HortTechnology 12(3):345–354.
12 Altieri, M.A. 1995. Agroecology. Westview Press, Boulder, CO.
13 Delate, K. and Cambardella, C. 1999. Comparison of organic and conventional rotations at the Neely-Kinyon Long-Term Agroecological Research (LTAR) site. Iowa State University Armstrong Research and Demonstration Farm Progress Report. College of Agriculture, Iowa State University, Ames, IA.
14 USDA-AMS. 2002. National Organic Program. Final rule: 7 CFR Part 205. US Department of Agriculture, Agriculture Marketing Service, Washington, DC. Available at Web site http://www.ams.usda.gov/nop (verified 10 July 2002).
15 Kelly, W.C. 1990. Minimal use of synthetic fertilizers in vegetable production. HortScience 25:168–169.
16 Niggli, U. and Lockeretz, W. 1996. Development of research in organic farming. In International Federation of Organic Agriculture Movements (IFOAM) (eds). Fundamentals of Organic Agriculture. IFOAM, Switzerland. p. 9–23.
17 Iowa Department of Agriculture and Land Stewardship (IDALS). 2001. Annual Survey on Organic Production. Iowa Department of Agriculture and Land Stewardship Diversification Bureau, Des Moines, IA.
18 Wander, M.M., Traina, S.J., Stinner, B.R., and Peters, S.E. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Science Society of America Journal 58:1130–1139.
19 Astier, M. 1990. Developing Low-input Energy Saving Vegetable Cropping Systems for Small Farmers in Salinas Valley. Association of Community Based Education, Washington, DC.
20 Altieri, M.A., Trujillo, J., Astier, M., Gersper, P., and Bakx, W. 1991. Low-input technology proves viable for limited-resources farmers in Salinas Valley. California Agriculture 45:20–22.
21 Astier, M., Gersper, P.L., and Buchanan, M. 1994. Combining legumes and compost: A viable alternative for farmers in conversion to organic agriculture. Compost Science and Utilization 2:80–87.
22 Organic Trade Association (OTA). 2001. OTA Newsletter. OTA, Greenfield, MA.
23 Dimitri, C. and Greene, C. 2002. Recent growth patterns in the US organic foods market. USDA–Economic Research Service, Washington, DC.
24 Delate, K., Duffy, M., Chase, C., Holste, A., Friedrich, H., and Wantate, N. 2003. An economic comparison of organic and conventional grain crops in a long-term agroecological research (LTAR) site in Iowa. American Journal of Alternative Agriculture 18(2):59–69.

25 Brumfield, R.G., Rimal, A. and Reiners, S. 2000. Comparative cost analyses of conventional, integrated crop management, and organic methods. HortTechnology 10(4):785–793.
26 Lampkin, N.H. and Padel, S. 1994. Organic farming and agricultural policy in Western Europe: An overview. In P. Midmore and N.H. Lampkin (eds). The Economics of Organic Farming: An International Perspective. CAB International, Wallingford, UK. p. 437–454.
27 Doran, J.W. and Peck, S. 2003. Editorial. American Journal of Alternative Agriculture 18(4):173.
28 Organic Farming Research Foundation (OFRF). 2002. Scientific Congress on Organic Agricultural Research. Available at Web site http:/www.ofrf.org/scoar/index.html (verified 10 July 2002).
29 National Research Council. 2003. Frontiers in Agricultural Research: Food, Health, Environment, and Communities. NRC–Committee on Opportunities in Agriculture. National Academies Press, Washington, DC.

Appendix 1: Topics and instructors in the Organic Crop Production course at Iowa State University.

Instructor	Topic
	Organic overview and soil health
Kathleen Delate, Iowa State University	Introduction to course: objectives and goals
Doug Karlen, USDA-ARS	Soil health as the basis for organic farming
Steve Hickenbottom, Producer	Crop rotations from a farmer's perspective
Maury Wills, IDALS Organic Program	Overview of IA organic program and certification
	Extra time for questions
	Composting, pasture health, integrated weed management
Tom Richard/Cindy Cambardella, Iowa State University	Composting for organic producers
Ken Moore, Iowa State University	Forages
Matt Liebman, Iowa State University	Principles of weed management for organic producers
	Pest management for organic producers
Jerry DeWitt, Iowa State University	Insect pest management for organic producers
Mark Gleason, Iowa State University	Disease management of fruits and vegetables
Gary Munkvold, Iowa State University	Disease management in agronomic crops
Greg Tylka, Iowa State University	Soybean cyst nematode management for organics
Joe Lynch, Producer	Pest management from a farmer's perspective
	Organic grain production and marketing
Kathleen Delate, Iowa State University	Organic grain research
Dale Farnham, Iowa State University	Corn research and information at ISU
Grace Welke, Iowa State University	Soybean varieties for the Tofu/Natto markets
David Brenner, USDA-ARS	Amaranth research and possibilities for organics
Jim Boes, Producer	Heartland organic marketing co-op, organic grain market
	Extra time for questions
	Organic fruits, vegetables, and herbs
Maury Wills, IDALS Organic Program	Organic apple production
Angela Tedesco, Producer	Organics—strawberries
Gary Guthrie, Producer	Organics—sweet corn and tomatoes
Larry Cleverley, Producer	Organics—garlic and greens
Jan Libby, Producer	Organics—broccoli and squash/pumpkins, INCA
Renne Soberg, Producer	Organic herb production and marketing
	Organic livestock production and marketing
Bill Welsh, Producer	Organic poultry production
Jim Russell, Iowa State University	Rotational grazing for organic producers
Dick Thompson, Producer	Organic cattle and hogs
Francis Thicke, Producer	Organic dairy
Ron Rosmann, Producer	Organic livestock production and marketing
Dave Carter, Private vet. services	Animal health practices

Appendix 2: ISU Organic Program Survey Results at the 4-year Milestone

	Percentage of respondents
Operation description	
Organic family farmer	53%
Transitioning family farmer (entire farm to organic)	11%
Mixed organic and conventional	19%
Organic corporate	1%
Conventional farmer with organic interest	6%
Other	8%
Organic acres farmed	
Less than 1	4%
1–5	5%
6–10	3%
11–20	4%
21–70	10%
71–120	19%
121–300	32%
301–500	10%
Other	10%
Organic crops and livestock	
Corn	21%
Soybean	22%
Oats	18%
Barley	4%
Wheat	4%
Livestock	8%
Vegetables	6%
Fruit	4%
Other	11%
Years in organic agriculture	
Thinking of starting	5%
In transition for 1 year	0%
In transition for 2 years	5%
In third year, certified organic	22%
4–6 years	41%
More than 6 years	17%
More than 6 years, not certified (≤US$5000/year)	3%
Primary markets for organic crops	
Organic cooperative	24%
Organic product broker	26%
Direct to consumer sales	17%
Direct to retail outlets	7%
CSA	5%
Farmers' market	4%
Wholesale produce markets	2%
On-farm sales	10%
Other	4%
Maintain fertility and soil quality	
Crop rotation with legumes	35%
Manure	24%
Compost from manure	17%
Compost/composted manure from purchased source	9%
Purchased organic fertilizers	6%
Other	6%

	Percentage of respondents
Environmental effects from organic practices	
Soil quality improvement	90%
Erosion mitigation	71%
Nitrate contamination reduction	55%
Water-holding capacity improvement	86%
Earthworm increase	88%
Crop performance improved	42%
Crop health improvement	79%
Pest insect reduction	69%
Beneficial insect enhancement	88%
Income increase from organic sales	
Not selling yet	10%
0–5% increase	12%
6–10% increase	18%
11–20% increase	30%
Other	19%
Organic extension events attended	
Field days	31%
Workshops	20%
Conferences	23%
ICN series on organics	8%
Special presentations	10%
Other	4%
Contact or activity	
Telephone or email contact	13%
Personal visits	9%
Field day	14%
Workshops	12%
Meeting/conference	17%
Publications	11%
ICN series on organics	9%
Other	1%
ISU organic publications read	
Overview of Organic Agriculture	13%
Weed Management in Organic Agriculture	22%
Growing Organic Soybeans on CRP Land	8%
Soil Quality in Organic Agriculture	12%
Other	1%
Most important organic activities	
Field days	18%
Publications	16%
Full-day workshops	14%
One-day conferences	14%
Half-day workshops	13%
ICN series	10%
Two-day conferences	9%
Other	1%
Organic activities that should be repeated (activities rated as most important)	
Organic weed management workshops	18%
Field days	18%
ICN series	10%
Composting workshops	13%
Certification workshops	11%
Organic fruit workshops	9%

	Percentage of respondents
Organic conference	15%
Other	1%
Future of ISU organic program	
Very important—needs to expand as budget allows	64%
Very important—need to retain as is	13%
Somewhat important	7%
Not important	0%
Other suggestions—all positive	3%

CSA, Community Supported Agriculture; ICN, Iowa Communication Network; ISU, Iowa State University.

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Phosphorous fertilizer efficiency and mycorrhizal infection in corn genotypes

Hayriye Ibrikci[1,*], John Ryan[2], Unzile Yildiran[1], Nuri Guzel[1], Ahmet C. Ulger[1], Gokhan Buyuk[1], Ebru Karnez[1] and Kursat Korkmaz[1]

[1]Cukurova University, Faculty of Agriculture, Adana 01330, Turkey.
[2]International Center for Agricultural Research in the Dry Areas (ICARDA), PO Box 5466, Aleppo, Syria.
*Corresponding author: hibrikci@cu.edu.tr or hibrikci@hotmail.com

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Abstract

In a world of limited resources and inexorable pressure to produce food for burgeoning populations, innovative approaches are needed to exploit these resources in a sustainable manner. Phosphorous (P) fertilizers are used extensively throughout the world for commercial crop production, and are a major factor in global food security. Yet, in developing countries, limited or no P fertilizer is used, often because of cost and infrastructure constraints, and this is therefore an impediment to sustainable production. The challenge facing soil scientists involved with soil and fertilizer P research is to produce adequate crops on inadequately fertilized soils in poorer countries and, at the same time, improve the efficiency of P use where excessive amounts are used, thus avoiding negative environmental impacts. Soil–plant fungi, especially arbuscular mycorrhizae (AM), may have a role in solving both horns of the P-use dilemma, since such associations have been shown to vary with plant species, and indeed genotypes within species, and to enhance crop utilization and uptake of P from soils low in soluble or available P. Therefore, as corn is an important feed and food crop in the Mediterranean coastal area of Turkey, we conducted two greenhouse studies to assess the P efficiency of a range of widely grown local corn genotypes and to establish the possible role of mycorrhizae in determining differences in observed P efficiency. The nine genotypes were grown with low to high P fertilizer rates (25–200 mg kg^{-1}) and assessed for P efficiency, based on visual observations, dry matter yield, and tissue P concentration. Two efficient and two inefficient genotypes were then grown with and without P fertilizer and added mycorrhizae. The experimental bulk soil had natural mycorrhizal colonization. The genotypes XL 72AA, DK 626 and LG 60, LG 2777 responded differently to both P and mycorrhizal infection. The efficient genotypes were more dependent on added P (twofold yield increase) and mycorrhizae than the inefficient ones. Thus, while mycorrhizal colonization is not a substitute for fertilizer use, it is complementary to it. While difficulties still remain for AM inoculation of crops in the field, more attention to mycorrhizae should be given by plant breeders in the process of crop improvement.

Key words: genotype assessment, P efficiency, mycorrhizal colonization, mycorrhizal dependency, corn

Introduction

Life on Earth, whether plant, animal or human, is dependent on the availability of phosphorus (P), which mediates all biological processes. Prior to the advent of the age of chemical fertilizers, beginning in the mid–19th century, agricultural productivity was invariably limited by the inherent fertility of the soil, especially in terms of P. World food production has largely kept pace with population growth, mainly due to widespread use of chemical fertilizers, thus keeping the Malthusian specter of widespread global hunger at bay, at least so far. Research on soil fertilizer/plant P has occupied the attention of many scientists for decades, and much has already become known about this most tantalizing subject[1]. However, some old problems still persist, due to the absence of P fertilizer use in developing countries, and indeed some new ones, due to excessive P use in other countries, especially in Europe and the USA[2]. With the advance in knowledge of soil biology[3] and plant breeding[4], it is appropriate to address future P research from a holistic approach. Given the fact that P fertilizer is an expensive agricultural input, the focus has to be on the efficient use of that resource.

Effective environmental and economical management of intensive agriculture requires detailed knowledge of the forms, amounts and chemical dynamics of P in soil[5].

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Continued and excessive P fertilizer applications may result in significant P accumulation in a soil profile[1,2,6]. Phosphorus movement down the profile and fixation by the soil particles are the result of soil and climatic factors and the form in which P is applied[7]. However, plant P availability is closely related to soil properties and amount of P in solution[6,8]. If efficiency of applied P is low, management practices and fertilizer applications become critical for optimum crop production. Generally, without intensive P fertilization, available P levels are inherently low in the southern part of Turkey, e.g., the Cukurova Region of Turkey, due to high clay and $CaCO_3$ contents, as is characteristic of the Mediterranean region in general[9], and limited research has been done on 'critical' available soil P levels for crops grown in the area[5].

Plant cultivars respond differently to soil and applied fertilizer P, i.e., the utilization efficiency differs. The P efficiency concept is defined as the ability of plants to produce relatively more yield (either biomass or grain) with suboptimal P availability[10]. Mechanisms that account for differential uptake of P by different plant species, or cultivars within a species, in any soil with a given level of available P, organic P, unavailable P or total P are largely genetically controlled. Various refinements of the broad concept of P efficiency have been developed[11]. The emphasis on P uptake and utilization is driven by the need to reduce fertilizer P input and thus extend global P reserves, and at the same time maintain crop yields[12]. Batten[12] looked at the P efficiency of wheat in terms of yield in relation to (1) kilograms of fertilizer applied to the crop; (2) P contained in the shoots; (3) P translocated to the grain; (4) the proportion of shoot P in the grain at harvest; and (5) P uptake per unit of root dry weight, or root-ratio efficiency.

Observations with other crops, such as corn (*Zea mays*), show genetic differences in some of the efficiency criteria. For instance, Fageria and Baligar[13] showed significant differences in corn genotypes for parameters such as plant height, shoot and root dry weights, and uptake and use efficiency of P when grown at either low or high levels of available P. Recognition of the genetic basis for differential efficiency of P fertilizer use underlies efforts to breed more efficient varieties of corn. This strategy includes the potential exploitation of possible genetic differences associated with mycorrhizal fungi, which are an indirect extension of root uptake mechanisms[14].

Given the limited information on the subject in the literature, it is not clear whether P efficiency is related to arbuscular mycorrhizal (AM) associations[15]. Arbuscular mycorrhizal fungi have been found on a vast variety of plant species. However, available information on the role of mycorrhizal symbiosis on the P availability and the assessment of P efficiency is inconclusive. Indeed, evidence to support a role of AM in P efficiency is contradictory. Thus, in a recent study, wild and cultivated lettuces were tested for mycorrhizal response, with no major differences being observed[16]. Plants seem to benefit most from AM associations under nutrient-poor conditions, especially when P is limiting[17]. The symbiotic root–fungal association is postulated to increase the uptake of relatively immobile nutrients, such as the micronutrients zinc and manganese, as well as P[18]. The increased P uptake with mycorrhizal infection has generally been associated with a decrease in the distance over which P ions diffuse to plant roots[19].

Interactions between crops in relation to AM and P seem to depend on the crop in question. Evidence suggests that P-efficient barley cultivars respond less to mycorrhizal infection than inefficient cultivars[20]. Mycorrhizal infection apparently alters the allocation of P in inefficient cultivars and effectively improves the efficiency of P utilization with respect to shoot growth. Mycorrhizal dependency is affected by root dry weight and root–shoot ratio (dry weight basis)[15]. While the literature of AM and P efficiency in corn is scanty, there are indications of considerable variability in mycorrhizal dependency of corn cultivars when grown in P-deficient soils, and this variability extends across improved and unimproved cultivars alike[21,22]. Mycorrhizal dependency has been shown to vary with crop species and within species. For instance, Khalil et al.[21] found that AM colonization was higher in soybean (*Glycine max*) than in corn (*Zea mays*). Even within corn cultivars, growth of an unimproved cultivar was unresponsive to infection, while another showed a fourfold increase in growth with infection. Mycorrhizae are believed to be involved in the P nutrition of corn[23]; understanding their functioning may assist in modifying management practices to maximize economic returns through increased fertilizer efficiency. Mycorrhizal colonization of corn hybrids and the quantity of extra-radical hyphae produced in the soil were shown to be greatest at the lowest levels of available P[24].

The purpose of this study was to assess growth response of corn genotypes to applied P, and examine the influence of mycorrhizal colonization and dependency of these genotypes, and thus to determine the possibility of using mycorrhizae at least as a partial alternative to P fertilizer use.

Materials and Methods

Experimental soil

Soil samples, taken from 0 to 30 cm depth of Typic Xerofluvent in the Cukurova region of Turkey, representative of much of the corn-growing land in the region, were dried, sieved through a 2-mm screen and placed in plastic pots of 2.5 kg capacity. Selected physical and chemical properties of the soil were recorded: clay texture, pH 7.7, low organic matter content (1.2%), high $CaCO_3$ content (30%), high in cation exchange capacity (30.4 Cmol kg^{-1}), and 8 mg kg^{-1} $NaHCO_3$-extractable P (Olsen).

Genotype assessment: P efficiency

The experiment was conducted under greenhouse conditions (night and day temperatures between 10 and 30°C) to evaluate P efficiency of nine local and commonly grown corn genotypes (P 3394, C 6127, LG 60, DK 626, Dracma, XL 72AA, P 3163, LG 2777 and P 3335), which were tested for P efficiency in terms of growth, dry matter production, and plant P content. Fertilizer P, as triple superphosphate [46% P_2O_5, main compound $Ca(H_2PO_4)_2$], was applied at four rates (25, 50, 100 and 200 mg kg^{-1}); other nutrients (nitrogen, potassium and micronutrients) were mixed with each pot at a basal rate prior to seeding. Eight seeds were planted, and subsequently thinned to three following germination. The experiment was arranged in a randomized complete block design with four replicates. The pots were periodically and manually watered with deionized water to keep the soil at approximately field capacity. Shoots were harvested after 10 weeks (6–10 leaves). Since only three corn plants were in a pot, there was no undue volume limitation in terms of root growth. Shoots were washed, dried and ground for chemical analysis. Samples were dry-ashed at 500°C overnight, and P in the extracted solution was determined colorimetrically[25]. Root samples were also washed and dried for dry matter determination.

Mycorrhizae: genotype efficiency

Following the genotype assessment, two inefficient (LG 60 and LG 2777) and two efficient (XL 72AA and DK 626) genotypes were selected to determine whether the efficiency is associated with mycorrhizal infection. This experiment was carried out under the same growth and greenhouse conditions (at a similar temperature range) as in the first experiment. Pots were treated without and with P (100 mg kg^{-1}) and mycorrhizae. Nitrogen, potassium and micronutrients (Zn, Fe, Mn and Cu), as a basal application similar to the first experiment, were mixed with the soil prior to seeding the pots.

Numbers of naturally occurring soil mycorrhizae in the bulk soil itself (159 mycorrhizal spores per 10 g soil), and numbers of mycorrhizae in the inoculum mixture were counted prior to the experiment[26]. A mycorrhizae inoculum-mixture consisting of *Glomus etunicatum*, *G. clarum*, *G. mosseae* and *G. caledonium* (the source is reported in Ortas et al., 2002[27]) was added to the mycorrhizae-receiving pots as 40 spores per 10 g in a soil–dry root medium. Batches of 2.5 kg soil were placed in pots, from which about 250 g soil was taken from top; then 100 g inoculum (soil–dry root medium) was placed evenly on the remaining soil and the 250 g soil was replaced in the pots to cover the inoculum.

Eight seeds were planted, and thinned to three after germination. The pots were arranged in a randomized complete block design with four replicates and watered periodically to field capacity during the experimental period. Shoots were harvested 10 weeks after planting, and then washed, dried and ground for chemical analysis, as in the first experiment.

Root samples were washed and subsampled, first for determination of mycorrhizal colonization and root length[28], and the remaining part was dried at 60–70°C for dry matter determination. The fresh samples of roots were saved in a mixture of ethanol:glacial acetic acid:formalin (250:13:15, by volume)[29] until the determination of mycorrhizal colonization, which was based on the procedure by Koske and Gemma (1989)[30]. The percentage of root colonization by mycorrhizae was calculated as: colonization % = 100 × total number of mycorrhizal-infected roots/total number of root in sample. Mycorrhizal dependency (MD) was calculated using the following formula[31]:

$$\mathrm{MD} = \frac{\text{dry weight}_{\text{mycorrhizal}} - \text{dry weight}_{\text{non-mycorrhizal}}}{\text{dry weight}_{\text{mycorrhizal}}} \times 100$$

The 'non-mycorrhizal soil' in this study was not strictly so, as the soil was not sterilized. It was in fact soil in a natural state with no added inoculum. Indeed, sterilized soil is rarely free of AM spores. It should be borne in mind that the original concept of mycorrhizal dependency, based on the above formula, does not strictly apply in this study. While there were 16 spores g^{-1} in the natural conditions, we were not aware of the viability of the spores or their potential for colonization.

Experimental data were analyzed by Analysis of Variance using the MSTAT-C (1988) computer program[32].

Results

Genotype assessment

All the parameters that reflect P use efficiency, i.e., shoot and root dry matter, and plant P concentration and uptake, varied among the nine corn genotypes in relation to P application rates. The most visible parameter, shoot weight, showed a wide range of responses (Table 1). Some genotypes consistently increased in yield, up to the maximum application rate of 200 mg kg^{-1}, while others showed little or no increase with added P.

Thus, based on the response patterns, the genotypes were arbitrarily categorized as 'efficient' or 'inefficient'. For example, the most responsive cultivar, DK 626, yielded only 5.9 g pot^{-1} at the lowest application rate (25 mg kg^{-1}) but 22.3 g pot^{-1} at the highest application rate (200 mg kg^{-1}). Other 'efficient' genotypes, such as XL 72AA and C 6127, exhibited a two- to 2.5-fold yield increase over the same P application range. The increase in yield, even among efficient genotypes, was not consistent with P application rates. Thus, a 'crossover' or 'differential' response occurred. In contrast to the 'efficient' genotypes that responded well to P, some genotypes showed little or no response to P, and were thus considered 'inefficient'. These included the P 3394 and LG 2777 genotypes. Other genotypes were intermediate in terms of P responses.

Table 1. Dry matter yield of corn genotypes with P application rates.

Genotypes (G)	P application (mg kg^{-1}) 25	50	100	200
	g pot^{-1}			
Efficient				
DK 626	5.9	8.0	13.1	22.3
C 6127	8.6	8.0	14.2	20.0
XL 72AA	7.5	9.2	13.3	19.1
Intermediate				
LG 60	5.9	7.0	14.6	14.6
Dracma	7.0	8.2	14.5	14.4
P 3163	6.8	9.0	9.0	11.9
P 3335	6.7	10.0	9.6	11.9
Inefficient				
LG 2777	3.9	5.7	7.6	7.7
P 3394	6.1	6.2	6.7	6.7
F Tests				
P	**			
G	**			
P × G	**			

** Indicates significance at the 0.01 probability level.

Table 2. Root dry matter responses of the corn genotypes with P application rates.

Genotypes (G)	P application (mg kg^{-1}) 25	50	100	200
	g pot^{-1}			
P 3163	4.0	5.5	5.9	10.3
XL 72AA	4.6	4.3	6.1	9.9
DK 626	2.9	4.2	7.3	9.7
Dracma	4.4	5.1	8.8	8.7
P 3335	3.7	8.0	7.5	8.1
LG 60	3.1	3.0	4.3	6.7
C 6127	4.8	4.2	5.7	6.4
LG 2777	2.3	3.2	4.3	4.0
P 3394	2.7	2.9	3.1	3.0
F Tests				
P	**			
G	**			
P × G	NS			

** and NS indicate significance at the 0.01 probability level and nonsignificance, respectively.

Table 3. Total P uptake of corn genotypes with P application rates.

Genotypes (G)	P application (mg kg^{-1}) 25	50	100	200
	g pot^{-1}			
DK 626	13.6	20.0	49.8	62.4
C 6127	25.1	23.2	34.1	58.0
XL 72AA	19.6	21.2	46.6	51.6
LG 60	15.3	23.8	54 .0	48.2
Dracma	14.7	18.9	46.4	36.0
LG 2777	15.6	15.4	31.9	34.7
P 3335	12.7	19.0	25.0	34.5
P 3163	13.6	17.1	31.5	33.3
P 3394	17.1	15.5	32.2	24.8
F Tests				
P	**			
G	**			
P × G	NS			

** and NS indicate significance at the 0.01 probability level and nonsignificance, respectively.

As shoot or above-ground plant material is dependent to a large extent upon the corresponding root mass, the effect of P application on root weight is presented (Table 2). As with shoot dry matter, there were significant effects of both P and genotypes, but no significant interaction between these main factors. Root dry matter was generally about 50% of the shoot dry matter, ranging from 2.3 to 10.3 g pot^{-1}. While root weights increased with applied P, and there were differences between genotypes at any P application rate, the ranking of genotypes was not consistent with P rates.

An examination of the P concentrations in the plant material showed some variation among genotypes at any P level, but little consistency between P levels, due to a dilution effect of plant growth. As P uptake is the integration of P concentration and dry matter yield, such data were much more consistent (Table 3) with significant effects of P and genotypes. Thus, the most efficient genotype, DK 626, showed increasing P uptake with P application rates, i.e., 13.6, 20.0, 49.8 and 62.4 mg pot^{-1} as P rates increased from 25 to 200 mg kg^{-1}. However, 'inefficient' genotypes such as P 3394 showed minimal increases in P uptake, i.e., from 17.1 to 24.8 mg kg^{-1}.

Mycorrhizal dependency

As a follow up to the initial genotype–P response study, a representative range of genotypes was selected for the subsequent mycorrhizal study. These were mainly based on P-use efficiency, despite the fact that the arbitrary classification of 'efficient' to 'inefficient' genotypes was based on only one factor, i.e., dry matter yield. In addition, agronomic factors such as disease resistance and field performance were considered. Thus, two clearly efficient genotypes (DK 626, XL 72AA) were selected along with one arbitrary inefficient one (LG 2777) and one intermediate one (LG 60).

When these four diverse genotypes were assessed for growth under various mycorrhizal and P-fertilized conditions, significant differences were apparent for shoot (Figure 1) and root (Figure 2) dry matter yields. A number of patterns were evident. There was a positive effect of mycorrhizae in the absence of applied

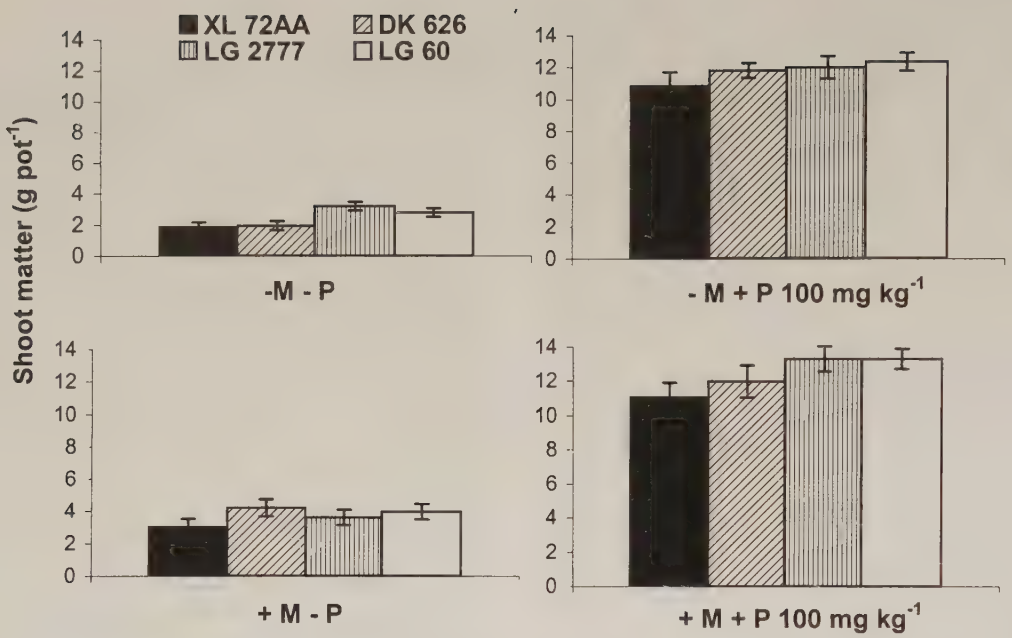

Figure 1. Genotypic above-ground growth response to mycorrhizae and P fertilizer. Bars indicate the standard deviation.

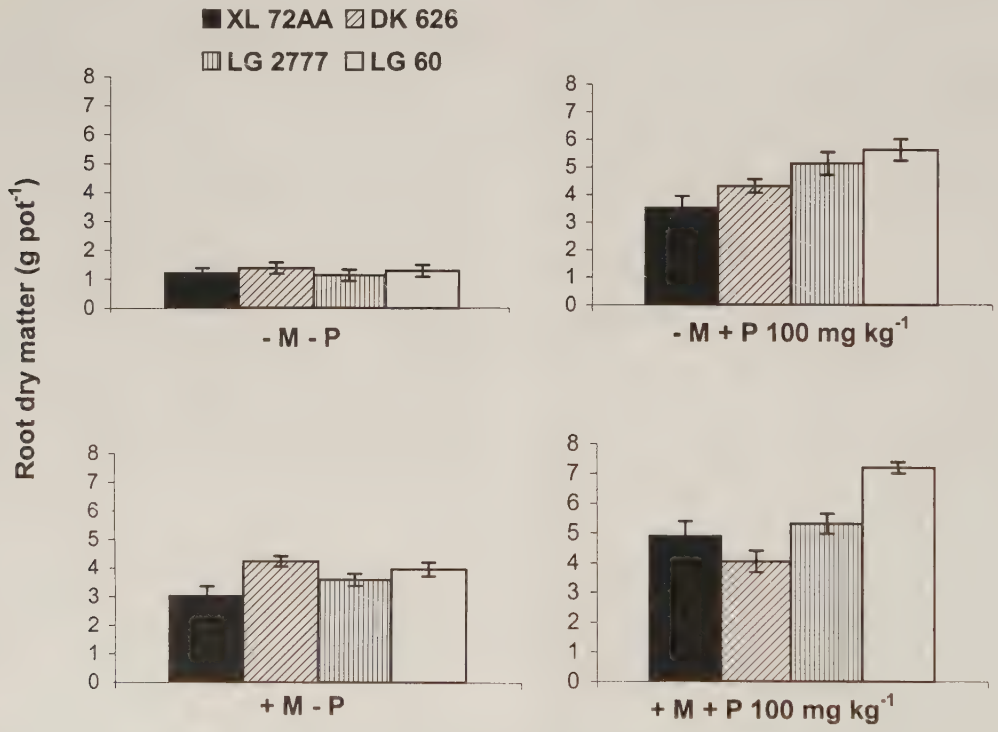

Figure 2. Genotypic root growth response to mycorrhizae and P fertilizer. Bars indicate the standard deviation.

P, as the comparatively low dry matter yields of all four cultivars were substantially increased by the mycorrhizae. However, under P fertilization (100 mg kg^{-1}), any effects of colonization were eliminated. In contrast to shoot growth, a differential effect of mycorrhizal infection was evident among genotypes for root growth under P fertilization.

In order to elaborate on the basis for differential effects of mycorrhizae on plant growth, detailed information on root length and root infection in relation to P uptake is presented (Table 4). Root infection (50–60%) with mycorrhizae was generally higher where the soil was inoculated, although a substantial amount of roots (25–40%) were infected in the uninoculated bulk soil.

Table 4. Mycorrhizal infection and P fertilizer effects on plant P uptake, root length and root colonization.

Mycorrhizae (M)	P (mg kg^{-1})	Genotype (G)	Plant P uptake (mg pot^{-1})	Root length (m pot^{-1})	Root colonization (%)
Not added	0	XL72AA	3.9	382	28.4
		DK 626	3.8	349	35.4
		LG 2777	6.4	779	36.8
		LG 60	5.5	737	41.4
	100	XL72AA	33.0	1638	32.8
		DK 626	36.7	1638	36.9
		LG 2777	29.2	3127	34.9
		LG 60	33.1	3118	37.8
Added	0	XL72AA	7.8	1171	54.0
		DK 626	12.3	611	54.5
		LG 2777	10.2	452	61.3
		LG 60	13.2	1135	60.5
	100	XL72AA	30.2	2146	47.6
		DK 626	35.3	1561	60.2
		LG 2777	34.5	3228	57.4
		LG 60	32.6	3923	55.5
	F Tests				
		M	**	**	**
		P	**	**	**
		G	**	**	**
		M × P	**	**	**
		G × M	NS	**	**
		P × G	NS	**	**
		M × P × G	**	**	**

** and NS indicate significance at the 0.01 probability level and nonsignificance, respectively.

Notwithstanding the difficulties of measuring or estimating root length, there was a clear effect of P fertilization regardless of the mycorrhizal status, i.e., about 3–4 times greater with P than without. Root lengths tended to be higher with mycorrhizal infection in the unfertilized soil, though not consistently so. A noteworthy feature was that the root lengths of the two 'efficient' genotypes were generally about half those of the intermediate and the inefficient genotypes.

In terms of P uptake data, there was again a major effect of P fertilization, i.e., 5–10 times greater uptake with P than without it. As with growth data, there was a significant effect of mycorrhizae in the nonfertilized soil, but not where P had been added. Uptake values following the mycorrhizal treatment alone were generally doubled. Again, as with shoot dry matter yield data, the effect of P fertilization masked that of the mycorrhizae. Given that corn responded to mycorrhizae only in the absence of fertilization, the calculated 'mycorrhizal dependency' presented in Figure 3 shows broad differences between the genotypes. That differences between the control and the mycorrhizal soil were significant suggest that the added AM spores were effective while the native spores in the 'non-mycorrhizal' (control) soil were relatively ineffective at colonization. Thus, the two 'efficient' genotypes had higher dependency values than the less efficient ones.

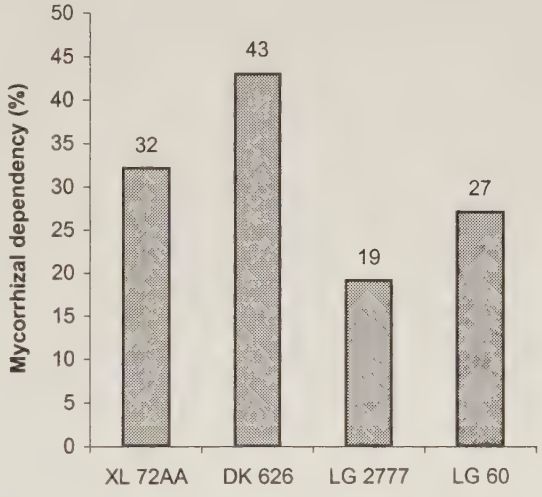

Figure 3. Mycorrhizal dependency of the genotypes without P fertilizer.

Discussion

It has long been established that genetics has a major role in determining differences in growth between crop cultivars[14,33]. The notion that collaboration between plant nutritionists, physiologists and breeders would lead to exploitation of these genetic differences had considerable

appeal. However, the advent of abundantly available economically affordable chemical fertilizers was to relegate genetic exploitation of nutritional differences to a secondary concern for many decades[4]. The past few decades have witnessed renewed interest in natural adaptation of crops to soils, with a reduction of chemical inputs. Our study was an attempt to find a niche for P-efficient corn genotypes and the possible complete or partial substitution of mycorrhizae for P fertilizers. As differences in plant growth following P fertilization are largely interpreted in terms of root morphology[10,34,35] and the extent of mycorrhizal infection[15,21,36], we adopted similar approaches.

As fertilization is so much a part of modern agriculture, it is important that agronomists and breeders, as well as farmers, be aware of the extent to which varieties or cultivars of any crop species respond to P fertilizer. Ideally, one should choose a variety that is efficient at low nutrient levels, and which shows significant growth responses when fertilizer is added. Our study identified at least three genotypes that meet the criteria for production efficiency, and thus add to the overall suite of agronomic characteristics that are vital to varietal assessment. It was clear from the study that at low fertility levels, differences between the corn cultivars are minor in terms of efficiency. Where maximum crop yields are the goal, one has to combine P fertilizer use and efficient P genotypes.

While the hypothesis that mycorrhizal infection could substantially replace fertilizer P needs of the crop was not borne out, the study did identify large genetic differences between genotypes, with possible significance for corn production in the region. That there were large differences in crop growth with mycorrhizal infection under low fertility (i.e., no added P) confirmed similar studies elsewhere[16,21,37]. Differences in efficiency in terms of growth were generally paralleled by root mass and P uptake. The obvious implications are that where soil fertility is low and where little or no P fertilizers are likely to be added, as in many resource-poor developing countries, mycorrhizae could have an influence in determining yields, *but that influence is limited*. However, it should be borne in mind that soil P reserves are also limited and cannot be 'mined' indefinitely. Where there is reliance on exploiting native soil P forms, a production decline is inevitable. Mycorrhizae may be attractive in situations where soil fertility has built up due to previous applications of P fertilizer, resulting in high levels of residual P available for exploitation.

Nor surprisingly, as noted in other studies[16,22], our study showed that when P fertilization was applied at higher rates, any differential effect of mycorrhizae was masked. With lower P rates, a response to AM cannot be ruled out[38]. Therefore, despite the potential value of mycorrhizae in natural ecosystems, their importance is diminished under modern fertilized conditions, at least for corn. In addition, some major issues remain as far as mycorrhizae are concerned. First, the identification of the various mycorrhizal populations and description of their extent is something that is poorly researched in many countries, whether developing or developed. Secondly, the intractable problem of technical feasibility of inoculation is as yet unclear. Thirdly, even if inoculation with mycorrhizae were feasible technically, the economics of its application are always questionable.

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References

1 Khasawneh, F.E., Sample, E.C., and Kamprath, E.J. (eds). 1980. The role of phosphorus in agriculture. ASA, CSSA, SSSA, Madison, WI, USA.

2 Tunney, H., Breeuwsma, A., Withers, P.J.A., and Ehlert, P.A.I. 1997. Phosphorus fertilizer strategies: Present and future. In H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds). Phosphorus Loss from Soil to Water. CAB International, Wallingford, UK. p. 177–203.

3 Bethlenfalvay, G.J. 1992. Mycorrhizae and crop productivity. In G.J. Bethlenfalvay and L.G. Linderman (eds). Mycorrhizae in Sustainable Agriculture. ASA Special Publication Number 54. ASA, Madison, WI. p. 1–27.

4 Gabelman, W.H. and Gerloff, G.C. 1983. The search for and interpretation of genetic controls that enhance plant growth under deficiency levels of a macronutrients. Plant and Soil 72:335–350.

5 Matar, A., Torrent, J., and Ryan, J. 1992. Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. Advances in Soil Sciences 18:81–146.

6 Ryan, J. and Rashid, A. 2003. Soil phosphorus. In Encyclopedia of Soil Science, in press.

7 Blake, L., Mercik, S., Koerschens, M., Moskal, S., Poulton, P.R., Goulding, K.W.T., Weigel, A., and Powlson, D.S. 2000. Phosphorus in soil, uptake by plants and balance in three European long-term field experiments. Nutrient Cycling in Agroecosystems 56:263–275.

8 Johnston, A.E. 2000. Soil and Plant Phosphate. International Fertilizer Industry Association, Paris, France.

9 Cooper, P.J.M., Gregory, P.J., Tully, D., and Harris, H.C. 1987. Improving water-use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture 23:113–158.

10 Yan, X., Lynch, J.P., and Beebe, S.E. 1995. Genetic variation for phosphorus efficiency of common bean in contrasting soil types. I. Vegetative response. Crop Science 35:1086–1093.

11 Blair, G. 1993. Nutrient efficiency – what do we really mean? In P.J. Randall, E. Delhaitze, R.A. Richards, and R. Munns, (eds). Genetic Aspects of Plant Mineral Nutrition. Kluwer Academic, Dordrecht, The Netherlands. p. 205–213.

12 Batten, G.D. 1992. A review of phosphorus efficiency in wheat. Plant and Soil 146:163–168.

13 Fageria, N.K. and Baligar, V.C. 1997. Phosphorus-use efficiency by corn genotypes. Journal of Plant Nutrition 20:1267–1277.

14 Marschner, H. 1998. Role of root growth, arbuscular

mycorrhiza, and root exudates for the efficiency in nutrient acquisition. Field Crops Research 56:203–207.

15 Azcon, R. and Ocampo, J.A. 1981. Factors affecting the vesicular-arbuscular infection and mycorrhizal dependency of thirteen wheat cultivars. New Phytologist 87:677–685.

16 Jackson, L.E., Miller, D., and Smith, S.E. 2002. Arbuscular mycorrhizal colonization and growth of wild and cultivated lettuce in response to nitrogen and phosphorus. Scientia Horticulturae 94:205–218.

17 Barea, J.M. 1991. Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. Advances in Soil Sciences 5:1–40.

18 Kothari, S.K., Marschner, H., and Romheld, V. 1991. Contribution of the VA mycorrhizal hyphae in acquisition of phosphorus and zinc by maize grown in a calcareous soil. Plant and Soil 131:177–185.

19 Bolan, N.S. 1991. A critical review on the role of mycorrhizal fungi in the uptake of phosphorus by plants. Plant and Soil 134:189–207.

20 Baon, J.B., Smith, S.E., and Alston, A.M. 1993. Phosphorus allocation in P-efficient and inefficient barley cultivars as affected by mycorrhizal infection. In N.J. Barrow (ed.). Plant Nutrition – From Genetic Engineering to Field Practice. Kluwer Academic, Dordrecht, The Netherlands. p. 319–322.

21 Khalil, S., Loynachan, T.E., and Tabatabai, M.A. 1994. Mycorrhizal dependency and nutrient uptake by improved and unimproved corn and soybean cultivars. Agronomy Journal 86:949–958.

22 Kaeppler, S.M., Parke, J.L., Mueller, S.M., Senior, L., Stuber, C., and Tracy, W.F. 2000. Variation among maize inbred lines and detection of quantitative trait loci for growth at low phosphorus and responsiveness to arbuscular mycorrhizal fungi. Crop Science 40:358–364.

23 Miller, M.H. 2000. Arbuscular mycorrhizae and the phosphorus nutrition of maize: A review of Guelph studies. Canadian Journal of Plant Science 80:47–52.

24 Liu, A., Hamel, C., Hamilton, R.I., and Smith, D.L. 2000. Mycorrhizae formation and nutrient uptake of new corn (*Zea mays* L.) hybrids with extreme canopy and leaf architecture as influenced by soil N and P levels. Plant and Soil 221:157–166.

25 Murphy, J. and Riley, J.P. 1962. A modified single solution method for determination of phosphate in natural waters. Analytica Chimica Acta 27:31–36.

26 Gerdmann, J.W. and Nicolson, T.H. 1963. Spores of mycorrhizal endogeny species extracted from soil by wet sieving and decanting. Transactions of the British Mycological Society 46:235–244.

27 Ortas, I., Ortakci, D., and Kaya, Z. 2002. Various mycorrhizal fungi propagated on different hosts have different effect on citrus growth and nutrient uptake. Communications in Soil Science and Plant Analysis 33:259–272.

28 Tennant, D. 1975. A test of a modified line intersect method of estimating root length. Journal of Ecology 63:995–1001.

29 Ortas, I. 1994. The effect of different forms of and rates of nitrogen and different rates of phosphorus fertilizers on rhizosphere pH and P uptake in mycorrhizal and non-mycorrhizal sorghum plants. PhD thesis, University of Reading, UK.

30 Koske, R.E. and Gemma, J.N. 1989. A modified procedure for staining roots to detect VAM. Mycological Research 92:486–505.

31 Plenchette, C., Fortin, J.A., and Furlan, V. 1983. Growth response of several plant species to mycorrhizae in a soil of moderate P fertility: 1. Mycorrhizal dependency under field conditions. Plant and Soil 70:191–209.

32 MSTAT-C, 1988. MSTAT-C version 1.2., A Microcomputer Program for the Design, Management, and Analysis of Agronomic Research Experiments. Michigan State University, East Lansing, MI.

33 Bruetsch, T.F. and Estes, G.O. 1976. Genotype variation in nutrient uptake efficiency in corn. Agronomy Journal 68:521–523.

34 Alves, V.M.C., Parentoni, S.N., Vasconcellos, C.A., Bahia Filho, A.F.C., Pitta, G.V.E., and Schaffert, R.E. 2001. Mechanisms of phosphorus efficiency in maize. In W.J. Horst et al. (eds). Plant Nutrition–Food Security and Sustainability of Agro-ecosystems. Kluwer Academic, Dordrecht, The Netherlands. p. 566–567.

35 Gahoonia, T.S., Nielsen, N.E., and Lyshede, O.B. 1999. Phosphorus (P) acquisition of cereal cultivars in the fields at three levels of P fertilization. Plant and Soil 211:269–281.

36 Smith, S.E., Robson, A.D., and Abbott, L.K. 1992. The involvement of mycorrhizas in assessment of genetically dependent efficiency of nutrient uptake and use. Plant and Soil 146:169–179.

37 Azcon, R., Gomez, M., and Tobar, R. 1992. Effects of nitrogen source on growth, nutrition, photosynthetic rate and nitrogen metabolism of mycorrhizal and P-fertilized plants of *Lactuca sativa* L. New Phytologist 121:227–234.

38 Lu, S. and Miller, M.H. 1989. The role of VA mycorrhizae in the absorption of P and Zn by in maize field and growth chamber experiments. Canadian Journal of Soil Science 69:97–109.

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Farmers' time investment in human capital: A comparison between conventional and reduced-chemical growers

Maria A. Boerngen* and David S. Bullock

Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, 1301 W. Gregory Drive, Urbana, IL 61801, USA.
*Corresponding author: boerngen@uiuc.edu

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Abstract

Many investigators have surmised that reduced-chemical and organic crop production require the input of a higher level of human capital than does conventional production. But no previous study has measured and compared whether the amounts of human capital growers use in managing their production systems differ across those systems. To provide the first measure of the time investment made in human capital by conventional and reduced-chemical farmers, we conducted a survey of 1000 Illinois households to obtain estimates of the amount of time spent by these different types of farmers to accumulate the human capital needed in their management practices. Conventional farmers reported spending just over 3 h week^{-1} 'keeping up' with information about their production practices, while reduced-chemical and organic farmers reported a time investment of nearly 4 h week^{-1}. This difference was found to be statistically significant, suggesting that chemical inputs and human capital may be economic substitutes. Farmers who adopted reduced-chemical practices reported a transition period of 1–2 years; during this period, they spent around 3 h week^{-1} learning about reduced-chemical technology. Adopters of organic practices also reported a transition period of 1–2 years; during this period, they invested 5 h week^{-1} learning about organic technology. The quantitative results of this study will be useful for future empirical work that investigates the potential costs and benefits of using subsidies to induce conventional farmers to switch to alternative production practices.

Key words: human capital costs, organic technology, profitability comparisons, reduced-chemical technology, transition costs

Introduction

Human capital is a vital input to agricultural production. Farmers add to their human capital stock (i.e., *learn*) in a variety of ways, including reading farm publications, attending field days, utilizing the Internet, listening to agriculture-focused radio or watching agriculture-focused TV, consulting university extension personnel and literature, and talking with their neighbors and input supply dealers. Such learning is necessary for farmers to successfully manage their 'everyday' production practices. 'Keeping up' in this way does more than simply prevent forgetting what has already been learned. For the consistent introduction of small technology changes—new seeds, new chemicals, etc.—into the market means that farmers who do not 'keep up' are soon 'left behind' by their economically more competitive neighbors. Moreover, sometimes farmers decide that merely 'keeping up' is not enough—in every modern farmer's life, several new and rather radical production technologies or practices have been introduced into the market. (Recent examples are no-till soybeans and global positioning system-based variable-rate fertilization technologies.) Before and soon after deciding to adopt such new production practices, farmers typically invest a concentrated amount of time and effort learning about them, to gain skills and knowledge specific to the technology under consideration.

Human capital is slightly different from other agricultural production inputs, in that typically a very large share of the full cost of its acquisition comes from the value of

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the time and effort required for learning, while only a very low share of the full cost comes from actually purchasing anything with cash or credit. Unfortunately, because it is rather difficult to measure the value of the time and effort used to acquire human capital, data on the full cost of acquiring agricultural human capital generally have not been collected. As a result, estimates of the cost of agricultural production generally include the purchase-cost of inputs such as fuel, chemicals and equipment, but omit costs generated by the investment of time in the acquisition of human capital.

The omission of human capital costs is especially noticeable in studies that have compared the costs or profits of organic or similar 'reduced-chemical' agricultural production practices with those of conventional production practices. (Often a distinction is made between 'certified organic' production practices and practices that cut down on the volumes of chemical inputs but do not do so enough to meet formal organic certification requirements. In this paper, we will use the term 'reduced-chemical' to denote both of these types of production. Where necessary, we will distinguish between these two types of production practices by using the term 'organic' specifically.) It is often proposed that farmers utilizing reduced-chemical production practices choose to invest more time in 'everyday' learning than farmers who use conventional production practices. In addition, it has been claimed that farmers who decide to make a transition from conventional to reduced-chemical farming typically pass through a prolonged period of intense learning before and soon after that decision is made. But differences in human capital costs under conventional and reduced-chemical production practices have not been quantified. This omission creates a gap in the large body of literature that makes economic comparisons between reduced-chemical and conventional production systems.

In this paper we report the first quantitative comparison of the time investment made in the accumulation of human capital by both conventional and reduced-chemical farmers. This measure will contribute to the literature on conventional and reduced-chemical agriculture by allowing for more complete estimates of production costs, and therefore will contribute to more accurate profitability comparisons between the two systems. This will aid other investigators who wish to include management cost differences in their economic analyses by providing a foundation on which calculations may be based, though more detailed analyses will be necessary in order to fully measure management costs. Our findings may also be useful in public debates about the amounts of public extension resources that should be dedicated to reduced-chemical agriculture. Information on the conversion from conventional to reduced-chemical production in some European countries, such as Sweden, seems relatively more available and easy to access than in the United States[1]. Indeed, it has been claimed that this lack of available information is an obstacle to the adoption of reduced-chemical methods in the US[2]. Our findings provide knowledge about how much such information might be demanded, which provides insight about how much of such information should be supplied publicly.

Literature Review

Human capital for 'everyday' management of conventional and reduced-chemical systems

The optimal level of human capital for the 'everyday' management of a reduced-chemical system is generally assumed to be higher than that needed for the 'everyday' management of a conventional production system. Crosson and Ostrov[3] stated, 'Clearly . . . alternative agriculture requires more management time and skill than conventional agriculture.' Chase and Duffy[4] noted that the reduced-chemical system is 'more complicated to manage', and therefore requires a higher level of managerial skill in order to be economically successful. Stinner and House[5] explained that reduced-chemical farming 'substitutes knowledge and management of ecological processes for large energy and chemical subsidies'. The National Research Council[6] concluded that reduced-chemical systems 'typically require more information, trained labor, time, and management skills per unit of production than conventional farming'. Similar observations about the higher skill level necessary for reduced-chemical farming have been made[7–11]. Despite these numerous studies having proposed that reduced-chemical farming is more human capital-intensive than conventional farming, no attempts have been made to quantify the 'everyday' human capital requirements of the two systems.

Human capital for the transition between conventional and reduced-chemical systems

In addition to its role in the 'everyday' management of both the conventional and reduced-chemical production systems, human capital also plays a vital role as farmers deal with the agronomic problems that frequently occur during the transition period that a farm must pass through while moving from a conventional to a reduced-chemical production system. Many authors have written about these agronomic problems[10,12–16]. For example, weed control is generally a significant problem during the conversion from conventional to reduced-chemical methods, as chemical herbicides are phased out of the management plan. Crops can suffer from nutrient deficiencies as commercial fertilizer is no longer applied. A 'yield penalty' usually results during the initial years of transition, in which crop yields are significantly lower than under conventional management. To cope with these problems, farmers must develop new management skills that are not needed under a system of chemical-intensive production. For example, citing research on pest infestation and soil fertility, Crosson and Ostrov[3] stated that '[e]liminating inorganic fertilizers and pesticides means that the farmer

must have enough understanding of the complex relationships among crops, weeds, insects, diseases, and determinants of soil fertility to suppress those things that threaten the crop and encourage those things that make it thrive'. The grower's knowledge and management skills are often cited as critical factors for coping with the biological effects of the transition to reduced-chemical production practices[10,12–14,17–19]. Yet, the learning process farmers undertake during the transition process has not been quantified.

Quantitative comparisons of the profitability of conventional and reduced-chemical systems

Implicit in all of the studies cited above is the assumption that human capital serves as an economic substitute for chemical inputs[20]. While this substitution means a reduced level of expenditure on inputs such as pesticides and fertilizers, it does not necessarily mean a reduction in overall production costs. There are costs associated with the gathering of information; unlike the costs of purchased inputs, the cost of human capital accumulation is difficult to quantify. Since reduced-chemical practices are generally assumed to have higher information requirements, and conventional practices are more reliant on purchased chemical inputs, the management costs associated with reduced-chemical and conventional systems are not derived from the same sources, nor are they necessarily equal.

A large body of literature attempts to compare the profitability of conventional and reduced-chemical agriculture[10,12,16,21–30]. Unfortunately, as Lockeretz[31] and Lee[32] pointed out, the influence of management ability and its associated costs are usually not included properly in economic comparisons between conventional and reduced-chemical systems. While these studies use data on crop yields and prices, and on variable production costs such as seed, chemical inputs, and field labor, the level and amount of management or human capital necessary to maintain conventional and reduced-chemical production methods usually have been assumed to be equal in economic analyses. In addition, the difficulties faced by growers considering or attempting the conversion from conventional to reduced-chemical methods usually are not included in such analyses. Therefore, these studies present an incomplete, and perhaps unreliable, picture of the comparative profitability of conventional and reduced-chemical production systems.

Lockeretz[33] claimed that it is impossible to know whether reduced-chemical farming actually requires more information than conventional farming. In this paper we attempt to overcome Lockeretz's skepticism. We provide the first empirical measure of the time investment made by conventional and reduced-chemical farmers in the accumulation of human capital, as described in the following section.

Methodology

To provide an empirical measure of the human capital choices made by conventional and reduced-chemical farmers, we mailed a survey to 1000 Illinois households identified from the Organic Crop Improvement Association (OCIA) membership list and the Environmental Working Group's database of farm subsidy recipients. Questions on the survey requested demographic information and data on the time farmers invest acquiring human capital. In order to have a sample in which organic farmers were adequately represented, we included the entire membership list of the Illinois chapter of the Organic Crop Improvement Association, excluding entries with out-of-state addresses and businesses for which no individual was listed, as well as one entrant who contacted us to decline participation. We sent questionnaires to 173 members of OCIA. On the recommendation of the Illinois Agricultural Statistics Service (B. Schwab, personal communication, December 12, 2001), 827 names were randomly selected from the Environmental Working Group's online database of farm subsidy recipients. We assumed that this source might contribute both conventional and reduced-chemical farmers to our sample.

Several statistical analyses were performed on the survey data to address the following questions:

- Do reduced-chemical and conventional farmers differ significantly with respect to the number of years they have been farming, their level of off-farm employment, their tendency to share management responsibilities with business partners, their age and level of education, and the proportion of their farmland that they own or rent?
- Are these demographic characteristics reliable predictors of a farmer's type?
- Do farmers using reduced-chemical production systems spend more time obtaining human capital used in their operations than do conventional farmers?
- What are the effects of demographic characteristics on the amount of time a farmer spends accumulating human capital needed to 'keep up' with the latest production practices?

Focus groups with both conventional and reduced-chemical farmers helped us decide what types of questions to ask in the survey, and a small-scale preliminary test of the survey enabled us to refine the questionnaire before it was mailed. As suggested by Dillman[34], we employed a four-contact mailing strategy, by which each participant received a preliminary letter, one copy of the survey, a follow-up postcard, and (if necessary) a second copy of the survey. Recipients who returned the completed questionnaire were entered in a draw for five cash prizes, each in the amount of $US100.

Demographic data were collected from survey respondents to allow for the measure of possible correlations between years of farming experience, off-farm employment, assistance from a partner, gender, age, education, and the adoption of reduced-chemical production. Survey

recipients were asked about off-farm employment, because such employment may increase a farmer's opportunity cost of time. A grower who faces this additional opportunity cost may find his optimal level of farm-related human capital to be lower than that of a farmer who does not hold an off-farm job in addition to the management of his farming operation. A farmer who shares a significant portion of his management responsibilities with a second person may spend less time gathering information than he would if he were the sole decision-maker on the farm. With two individuals making management choices, they can divide the task of accumulating human capital between them. Therefore, we also asked survey participants if they shared decision-making responsibilities with another person.

A survey item addressing land tenure was included because McCann et al.[35] found that farmers who rent their acreage tend to be less likely to adopt conservation practices. This corroborates what we learned from members of the conventional farmer focus group. According to those individuals, rented farmland is in great demand in Illinois, and tenant farmers are pressured to maintain clean, tidy-looking fields. The proliferation of weeds is a common problem during the period of transition to reduced-chemical production, possibly causing fields to appear messy and unkempt to a landlord. Because this aesthetic problem may be a deterrent to the adoption of reduced-chemical methods, we wanted to investigate a possible connection between land tenure and the adoption of reduced-chemical production.

Recipients were asked to identify new production methods they had adopted, including (non-organic) reduced-chemical and organic methods. They were then asked to identify the sources of information consulted when investigating new technologies (the list of possible sources was generated from the suggestions of the two focus groups), the length of the time period the farmer spent investigating these new technologies, and the amount of time (hours per week) they spent consulting various information sources as they investigated the new technologies. These survey questions provided an empirical measure of the time investment farmers make in the accumulation of human capital when they are investigating and/or adopting new production practices, including reduced-chemical and organic technologies.

Participants in the focus groups explained that the conversion to new production practices requires an initial period of intensive learning at the beginning of the transition phase. They claimed that as the grower becomes more experienced with the new technology, the amount of time he spends acquiring information about it declines. Therefore, we asked survey participants about their day-to-day information-gathering habits when they are not engaged in the adoption of new technologies. We asked them to identify the sources they use to 'keep up' with information about production practices, and then to provide an hour-per-week measure of the time spent with these sources. This allowed for a comparison of the time investment made by the farmers during periods of transition and during periods when they were not incorporating new technologies into their production systems. This also provided a comparison of the 'everyday' human capital needs of conventional and reduced-chemical farmers and allowed us to measure the relative 'information-intensity' of the two systems, as discussed in the literature review.

Results

We received 210 completed questionnaires, with 76 returned by recipients from the Organic Crop Improvement Association and 134 returned by recipients from the Environmental Working Group database. Based on the information they provided, respondents were divided into two types: 'reduced-chemical' farmers were those individuals who indicated they had adopted reduced-chemical and/or organic production practices, and 'conventional' farmers were the individuals who indicated that they had adopted neither of those technologies. We classified 109 survey participants as reduced-chemical growers, and 101 as conventional farmers. Of the 210 respondents, 206 provided information on the crops and livestock that they raise. Sixty-one reduced-chemical growers reported that they raised only field crops, fruits, vegetables or herbs; 3 reduced-chemical growers raised only livestock; and 42 had both crop and animal husbandry operations. Similarly, 60 conventional growers reported that their operations included only field or specialty crops; 3 conventional growers raised only livestock; and 37 raised both crops and livestock. The mean size of the reduced-chemical farms was 593 acres, while the conventional farms had a mean size of 630 acres. This size difference was not found to be statistically significant.

Summary of demographic characteristics

As illustrated by Table 1, the typical survey respondent had been farming for 15–20 years, was holding a part-time job off the farm, did not have a business partner sharing significantly in the farm's management or decision-making, was male, was between 51 and 60 years of age, attended college but did not have a degree, and rented a majority of the land he farmed. The mean scores on the demographic characteristics for the conventional and reduced-chemical groups did not differ significantly from one another, with two exceptions. The typical conventional grower in the sample had a business partner sharing in management decisions, and the typical reduced-chemical grower in the sample had received an associate's degree. The fourth column of Table 1 reveals that these two characteristics were the only ones in which the conventional and reduced-chemical farmers were significantly different from one another. Because the number of female respondents was extremely low (14 out of 210), we did not consider gender in the following statistical analyses.

Table 1. Demographic characteristics of survey respondents.

	Conventional farmers[1]	Reduced-chemical farmers[1]	*t* test statistic	All farmers[1]
Years farming[2]	4.36 ± 1.133 ($n=100$)	4.370 ± 1.181 ($n=108$)	(0.06) 206 df	4.365 ± 1.155 ($n=208$)
Off-farm employment[3]	0.827 ± 0.908 ($n=98$)	0.752 ± 0.884 ($n=109$)	(0.60) 205 df	0.787 ± 0.894 ($n=207$)
Business partner[4]	1.459 ± 0.501 ($n=98$)	1.575 ± 0.497 ($n=106$)	(1.66)** 202 df	1.520 ± 0.501 ($n=204$)
Gender[5]	1.050 ± 0.218 ($n=101$)	1.083 ± 0.277 ($n=109$)	(0.96) 208 df	1.067 ± 0.250 ($n=210$)
Age[6]	3.842 ± 1.468 ($n=101$)	3.743 ± 1.189 ($n=109$)	(0.54) 208 df	3.790 ± 1.328 ($n=210$)
Education level[7]	3.12 ± 1.313 ($n=100$)	3.569 ± 1.499 ($n=109$)	(2.29)** 207 df	3.354 ± 1.427 ($n=209$)
Land tenure[8]	0.425 ± 0.497 ($n=87$)	0.495 ± 0.503 ($n=91$)	(0.92) 176 df	0.461 ± 0.500 ($n=178$)

[1] Scores are mean ± standard deviation.
[2] 1 = 5 years or less; 2 = 5–10 years; 3 = 10–15 years; 4 = 15–20 years; 5 = 20 years or more.
[3] 0 = not employed off-farm; 1 = employed part-time off-farm; 2 = employed full-time off-farm.
[4] 1 = has business partner; 2 = no business partner.
[5] 1 = male; 2 = female.
[6] 1 = 18–30 years; 2 = 31–40 years; 3 = 41–50 years; 4 = 51–60 years; 5 = 61–70 years; 6 = 71 years or older.
[7] 1 = grade school or less; 2 = high school or equivalent; 3 = some college; 4 = associate's degree; 5 = bachelor's degree; 6 = master's degree or higher.
[8] 0 = rents more than 50% of farmland; 1 = owns 50% or more of farmland.
Absolute values of *t* statistics in parentheses; df, degrees of freedom.
* Significant at 10%; ** significant at 5%; *** significant at 1%.

Demographic characteristics as predictors of farmer type

Previous studies have addressed possible interactions between farmers' age, educational levels, number of years' farming experience, and land tenure and their adoption of reduced-chemical production practices[9,11,35]. To compare our results with theirs, we conducted a logit regression measuring the effects of these demographic characteristics on the probability that a farmer adopts reduced-chemical production practices. For the purpose of this analysis, Type 1 represents reduced-chemical growers, and conventional farmers are represented by Type 0. The results of the logit regression are presented in Table 2.

Based on the choice intervals listed in the questionnaire for these demographic characteristics, the odds ratios are interpreted as follows:

- A 5-year increase in the number of years an individual has farmed increased his probability of being Type 1 (reduced-chemical) by about 11%.
- A 10-year increase in a farmer's age reduced his probability of being Type 1 by approximately 4%.
- An incremental increase in his education level (i.e., from 'high school or equivalent' to 'some college', or from 'some college' to 'associate's degree') increased a farmer's probability of being Type 1 by approximately 29%.
- An individual who owned at least 50% of his farmland was about 43% more likely to be a reduced-chemical farmer.

Table 2. Logit model measuring a farmer's likelihood of adopting reduced-chemical practices.

Type	Odds ratio	Robust standard error	*z* statistic
Years farming	1.110	0.174	(0.67)
Age	0.960	0.134	(0.29)
Education	1.292	0.161	(2.06)**
Land tenure	1.425	0.471	(1.07)

Absolute value of *z* statistics in parentheses.
* Significant at 10%; ** significant at 5%; *** significant at 1%.

While these odds ratios illustrate the relationship between farmer characteristics and his likelihood of adopting reduced-chemical practices, the only variable that had a significant effect on likelihood was his education level ($P=0.040$). Including a farmer's level of off-farm employment and his sharing of management decisions with a business partner in the logit regression changed the odds ratios slightly, but the direction of the relationships between number of years farming, age, education, and land tenure and the likelihood of adoption did not change with the inclusion of these additional explanatory variables. Likewise, the farmer's education level remained the only variable that significantly affected the likelihood of adopting reduced-chemical technologies ($P<0.05$).

Measures of the amount of time farmers invest in learning

Because we are interested in both 'everyday' human capital and the amount of human capital necessary for the adoption of new production practices, survey recipients were asked to identify the amount of time they spent learning about new technologies that they had already adopted, as well as how much time they devoted to 'keeping up' with information about production practices they were currently using. We calculated the mean amount of time the two types of farmers (conventional and reduced-chemical, as previously defined) spent acquiring human capital needed for the management of their 'everyday' production practices, as well as the mean amount of time that adopters of reduced-chemical and organic practices devoted to learning about those technologies. Survey recipients were asked to indicate the amount of time they spent each week using various sources of information, such as farm publications, field days, the Internet and agriculture-focused radio, by selecting from among categories (e.g., 'Zero hours', '1 hour or less per week', 'More than 1 but less than 2 hours per week', etc.) These raw data were used to calculate weekly time investment in learning by using the *minimum* contribution made by each selection to the total weekly amount of time. For example, 'more than 1 but less than 2 hours per week' contributed 1 h to this total. The category '1 hour or less per week' was assumed to contribute 0.5 h to this calculation. These calculations allow us to compare quantitatively the human capital choices made in the management of conventional and reduced-chemical production systems. The results are presented below.

The role of human capital in day-to-day management

As illustrated in Table 3, conventional farmers spent a mean of 3.29 h week^{-1} in 'everyday' learning, and reduced-chemical farmers devoted a mean of 3.94 h to learning each week. It is clear that the point-estimate of the difference in 'everyday' learning between the two farmer types was slight (less than 1 h week^{-1}). However, this difference was statistically significant ($P = 0.0676$), which suggests that the management of a reduced-chemical production system requires more human capital than the management of a conventional system. This may imply that chemical inputs and human capital are economic substitutes. However, there are other possible explanations for this phenomenon. For example, growers who adopt reduced-chemical practices may also simply be more interested in learning, which induces them to devote more time to collecting information on an 'everyday' basis. The higher education level of the reduced-chemical group suggests that these growers may be more efficient learners, and they may therefore be more disposed to gathering information. Adopters of reduced-chemical technologies may make simultaneous decisions to increase their level of knowledge *and* reduce their level of chemical input usage, without one decision causing the other. It appears that farmers who use reduced-chemical practices substitute human capital for chemical inputs. But to state with certainty that chemical inputs and human capital are *economic* substitutes for one another requires the identification of a two-way causal relationship between a reduction in chemical input usage and an increase in the chosen level of human capital. Such a conclusion cannot be drawn from the data we have accumulated.

Table 3. Mean 'everyday' time investment in human capital, by type.

Hours per week invested in human capital[1]		
Conventional	**Reduced-chemical**	***t* test statistic[2]**
3.3 ± 2.8	3.9 ± 2.9	(1.50)*

[1] Scores are mean ± standard deviation.
[2] One-tailed hypothesis test: H_A: reduced-chemical mean > conventional mean.
Absolute value of *t* statistic in parentheses.
* Significant at 10%; ** significant at 5%; *** significant at 1%.

Demographic characteristics' influence on 'everyday' learning

Multiple linear regression analysis revealed the effects that farmer type and demographic characteristics had on growers' mean 'everyday' human capital-gathering habits. The farmer's 'type' (i.e., conventional or reduced-chemical) was included in these analyses to estimate possible differences in the human capital choices made by the two groups of growers. The number of years each respondent had been engaged in farming was included because of the possibility that the more farming experience an individual had, the less his need for new information. Off-farm employment may have affected the amount of time spent learning because a farmer holding another job might have had less time to devote to accumulating information (i.e., had a higher opportunity cost of learning). If a farmer shared his management decisions with a partner, the task of collecting information used in decisions about current production practices may have been divided between the two individuals, resulting in each of them spending less time in this activity than they might otherwise have spent if they managed operations without help. A younger farmer may spend more time learning about his current farming practices because he has less experience upon which to rely (possible interactions between a grower's age and years of farming experience are discussed below). Finally, a farmer who has attained a higher level of education may devote more time to acquiring human capital because he is a more efficient learner (i.e., has a lower opportunity cost of learning). The results of this analysis are presented in Table 4.

Table 4. Effects of type and demographic characteristics on 'everyday' learning.

Weekly learning time	Coefficient	*z* statistic
Type	–1.999	(1.41)
Years farming	0.429	(0.66)
Off-farm employment	–0.352	(0.45)
Business partner	–0.202	(0.15)
Age	–1.252	(1.90)*
Education	0.202	(0.41)
Constant	4.669	(1.00)

Observations: 176.
Absolute value of *z* statistics in parentheses.
* Significant at 10%; ** significant at 5%; *** significant at 1%.

Table 5. Mean weekly time investment in human capital during the transition to reduced-chemical and organic technologies[1].

	Reduced-chemical[2]	Organic[2]	*t*-test statistic[3]
Minimum hours per week	2.9 ± 2.5	5.2 ± 6.3	(2.55)***

[1] Twenty-eight respondents had adopted both reduced-chemical and organic technologies.
[2] Scores are mean ± standard deviation.
[3] Adoption of organic technology required a significantly greater amount of learning than adoption of reduced-chemical technology. Absolute value of *t* statistics in parentheses.
* Significant at 10%; ** significant at 5%; *** significant at 1%.

Regressing the respondents' weekly time investment in learning about their current farming practices on farmer type and demographic characteristics revealed that a farmer's age had a significant effect on how much time he devoted to keeping up with information about the technologies he uses ($P = 0.057$). Specifically, each approximately 10-year increase in farmer age reduced his weekly learning time by approximately 1.25 h. This result may arise from an older individual having a shorter horizon of time within which he expects to receive payoffs from the time he invests in learning. In addition, he may already have gained what he believes to be a sufficient amount of knowledge about his farming practices, and therefore may have chosen to devote less time to learning as he grows older.

Multicollinearity among the demographic characteristics used as explanatory variables in the regressions detailed above will weaken the results of the analyses. Following the recommendations of Hamilton[36], we ran several diagnostic tests to check for multicollinearity between the explanatory variables. We regressed each explanatory variable on the others and calculated $(1 - R^2)$ from each of these subsequent regressions, to determine how much variation in each explanatory variable is independent of the others. We found that approximately 96% of the variation in *Type* is independent of the other explanatory variables. Similarly, approximately 79%, 87%, 95%, 73% and 84% of the variance of *Years farming*, *Off-farm employment*, *Business partner*, *Age* and *Education*, respectively, are independent of the other explanatory variables. In addition, we utilized Stata's vif command to generate the mean 'variance inflation factor' (VIF) after each regression. This is another post-regression diagnostic tool that is useful in detecting multicollinearity. The mean VIF values for these regressions were between 1.09 and 1.20. Chatterjee et al.[37] suggest that a mean VIF no larger than 1 indicates the presence of no multicollinearity. However, following Hamilton's example[36], we concluded that the high proportion of independent variation among the explanatory variables, together with mean VIF values just slightly greater than 1, indicates that multicollinearity was not present in the data.

The role of human capital during the adoption of new technologies

Survey respondents who indicated that they had adopted reduced-chemical practices reported a mean transition period of 1–2 years from when they began to seriously investigate this technology to when they adopted it; during this period, they spent a mean of 3 hours each week learning about reduced-chemical technology. Adopters of organic practices reported that a mean of 1–2 years elapsed between when they started learning about organic practices and when they adopted them. During this transition period, they invested 5 hours each week learning about organic technology. As presented in Table 5, 28 farmers had adopted both reduced-chemical and organic technologies. These growers invested more than two additional hours per week building human capital during the adoption of organic practices than during the adoption of reduced-chemical practices. The statistical significance of this difference suggests that the adoption of organic technology requires more new human capital than the adoption of reduced-chemical technology.

Concluding Remarks

Implications and relevance of results

By providing the first measure of the time investment made in human capital by conventional and reduced-chemical farmers, our data will aid researchers who wish to include management cost differences in their economic analyses. We have also measured the length of the transition period during which growers adopt various technologies, the amount of time they spend learning each week during this transition period, and the human capital demands that accompany use of these technologies on an 'everyday' basis once adoption is complete. Our results suggest that while the day-to-day human capital demands of a reduced-chemical production system are slightly higher than those

of a conventional system, the difference is relatively small, about 1 h week^{-1}. That is, once the transition period between the conventional technology and the reduced-chemical technology is complete, farmers using reduced-chemical production practices only spend about 1 h week^{-1} more 'keeping up' with the latest information about production practices than do farmers using conventional practices. In addition, the adoption of any technology with which the grower is not familiar requires him to build a new set of skills and knowledge during a 'learning transition period'. We found that a period of 1–2 years generally elapses between the time when farmers begin seriously to investigate organic practices and when these practices are adopted. During this time, growers spend at least 5 hours each week learning about organic production. These numbers imply that the adoption of organic production requires farmers to invest a total of 260–520 h learning about the technology before it is adopted. The opportunity cost of these hours affects a farm's profits, as time the grower devotes to building organic-specific human capital reduces the amount of time he can spend in activities such as refining his other production practices or generating outside income. These transition period learning costs are in addition to the 'yield penalty' that usually occurs during the period in which farmers converting to organic practices are building the fertility levels of their soils and developing reduced-chemical pest-management strategies.

Limitations of this study and extensions for future research

A value must be placed on farmers' time in order to calculate the level of subsidy required to compensate growers for their human capital accumulation during the transition to reduced-chemical production practices. Therefore, additional quantitative work is needed to estimate farmers' opportunity cost of time. In addition, the value of the yield penalty must be calculated; added to the compensation for farmers' time, this will provide an estimate of the conversion subsidy needed to encourage more farmers to adopt reduced-chemical technologies. While we demonstrate that conventional and reduced-chemical growers invest differing amounts of time in the accumulation of human capital, there are cost differences between the two systems that are generated in other ways as well. For example, reduced-chemical production typically requires a higher input of labor for such operations as mechanical weed control, and a full economic comparison of the two systems will require that these costs are captured as well. The dataset built from survey responses provides information on farm size and the types of crops and livestock raised on the recipients' farms. More sophisticated analyses of human capital needs that include these variables could enable researchers to generate policy recommendations targeted to specific segments of the farm population. For example, certain crops such as corn typically receive high levels of nitrogen fertilizer, which contributes to nitrate pollution in surface water. Focusing research on the quantities of human capital required for corn growers to convert to reduced-chemical production practices would aid in the establishment of educational programs to provide the necessary information about reduced-chemical practices, as well as in calculating conversion subsidies sufficient to cover the cost of the farmers building the skills they need to succeed with reduced-chemical management.

Our survey covered the farm population of Illinois, but larger-scale efforts could generate similar data across a wider area to gauge the time investment made in human capital by farmers on a regional or even a national basis. These data would be useful in comprehensive profitability comparisons that could then provide the foundation for regional- or perhaps federal-level policy recommendations. For example, reduced-chemical technologies compete favorably with conventional production in drought-prone areas. Focusing efforts on the human capital needs of growers living in such areas would be useful in drafting economic incentive programs designed to encourage these farmers to adopt reduced-chemical production practices, while compensating them for the time they would invest in learning about these practices. Survey efforts in Europe could address the common hypothesis that conversion subsidies are not critical for encouraging adoption of reduced-chemical practices there, and could also shed light on the question of greater information availability outside of the US.

The reduced-chemical growers in our sample had achieved a significantly higher level of education than the conventional growers we surveyed. As previously stated, a farmer who has attained a higher level of education may devote more time to acquiring human capital because he is a more efficient learner (i.e., has a lower opportunity cost of learning). On the other hand, this difference may imply that reduced-chemical growers choose to devote more time to building human capital because they simply find more enjoyment in learning and building human capital. Further work could analyze this difference between the two groups more carefully.

Final thoughts

While Lockeretz[33] claimed that 'we can only speculate' about differences in human capital needs among conventional and reduced-chemical farmers, it is now clear that measures of these needs are obtainable from the farm population. Our results suggest that human capital and chemical inputs may be economic substitutes for one another. But to state with certainty that chemical inputs and human capital are *economic* substitutes for one another requires the identification of a two-way causal relationship between a reduction in chemical input usage and an increase in the chosen level of human capital. Such a conclusion cannot be drawn from the data we have

accumulated. The length of the 'learning transition period' to organic production, and the number of hours each week that farmers spend learning about this technology during the transition period, imply that a farm's profits may be significantly affected by the building of new human capital during the adoption of organic production. By compensating farmers for both the yield penalty that is commonly seen during the transition period and the value of the time they must spend learning about organic technology, conversion subsidies may encourage more farmers to adopt reduced-chemical practices.

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References

1 Lohr, L. and Salomonsson, L. 2000. Conversion subsidies for organic production: Results from Sweden and lessons for the United States. Agricultural Economics 22:133–146.
2 Andrew, J.C. III. 1987. Making the transition to low input agriculture: A farmer's perspective. American Journal of Alternative Agriculture 2:17–18.
3 Crosson, P. and Ostrov, J.E. 1990. Sorting out the environmental benefits of alternative agriculture. Journal of Soil and Water Conservation 45:34–41.
4 Chase, C. and Duffy, M. 1991. An economic comparison of conventional and reduced-chemical farming systems in Iowa. American Journal of Alternative Agriculture 6:168–173.
5 Stinner, B.R. and House, G.J. 1987. Role of ecology in lower-input, sustainable agriculture: An introduction. American Journal of Alternative Agriculture 2:146–147.
6 National Research Council 1989. Alternative Agriculture. National Academy Press, Washington, DC. p. 9.
7 Batie, S.S. and Taylor, D.B. 1989. Widespread adoption of non-conventional agriculture: Profitability and impacts. American Journal of Alternative Agriculture 4:128–134.
8 Edwards, C.A. 1987. The concept of integrated systems in lower input/sustainable agriculture. American Journal of Alternative Agriculture 2:148–152.
9 Egri, C. 1999. Attitudes, backgrounds and information preferences of Canadian organic and conventional farmers: Implications for organic farming advocacy and extension. Journal of Sustainable Agriculture 13:45–72.
10 Hanson, J.C., Lichtenberg, E., and Peters, S.E. 1997. Organic versus conventional grain production in the mid-Atlantic: An economic and farming system overview. American Journal of Alternative Agriculture 12:2–9.
11 Lasley, P., Duffy, M., Kettner, K., and Chase, C. 1990. Factors affecting farmers' use of practices to reduce commercial fertilizers and pesticides. Journal of Soil and Water Conservation 45:132–136.
12 Dabbert, S. and Madden, P. 1986. The transition to organic agriculture: A multi-year simulation model of a Pennsylvania farm. American Journal of Alternative Agriculture 1:99–107.
13 Liebhardt, W.C., Andrews, R.W., Culik, M.N., Harwood, R.R., Janke, R.R., Radke, J.K., and Rieger-Schwartz, S.L. 1989. Crop production during conversion from conventional to low-input methods. Agronomy Journal 81:150–159.
14 Mallory, E.B., Posner, J.L., and Baldock, L.O. 1998. Performance, economics, and adoption of cover crops in Wisconsin cash grain rotations: On-farm trials. American Journal of Alternative Agriculture 13:2–11.
15 Scow, K.M., Somasco, O., Gunapala, N., Lau, S., Venette, R., Ferris, H., Miller, R., and Shennan, C. 1994. Transition from conventional to low-input agriculture changes soil fertility and biology. California Agriculture 48:20–26.
16 Smolik, J.D. and Dobbs, T.L. 1991. Crop yields and economic returns accompanying the transition to alternative farming systems. Journal of Production Agriculture 4:153–161.
17 Dabbert, S. 1994. Economics of conversion to organic farming: Cross-sectional analysis of survey data in Germany. In N.H. Lampkin and S. Padel (eds). The Economics of Organic Farming. CAB International, Wallingford, UK.
18 Francis, C.A. 1990. Practical applications of low-input agriculture in the Midwest. Journal of Soil and Water Conservation 45:65–67.
19 Padel, S. and Lampkin, N.H. 1994. Conversion to organic farming: An overview. In N.H. Lampkin and S. Padel (eds). The Economics of Organic Farming. CAB International, Wallingford, UK.
20 Francis, C.A. and King, J.W. 1988. Cropping systems based on farm-derived, renewable resources. Agricultural Systems 27:67–75.
21 Diebel, P.L., Williams, J.R., and Llewelyn, R.V. 1995. An economic comparison of conventional and alternative cropping systems for a representative northeast Kansas farm. Review of Agricultural Economics 17:323–335.
22 Dobbs, T.L. and Smolik, J.D. 1996. Productivity and profitability of conventional and alternative farming systems: A long-term on-farm paired comparison. Journal of Sustainable Agriculture 9:63–79.
23 Hanson, J.C., Johnson, D.M., Peters, S.E., and Janke, R.R. 1990. The profitability of sustainable agriculture on a representative grain farm in the Mid-Atlantic region, 1981–89. Northeast Journal of Agricultural and Resource Economics 19:90–98.
24 Karlen, D.L., Duffy, M.D., and Colvin, T.S. 1995. Nutrient, labor, energy, and economic evaluations of two farming systems in Iowa. Journal of Production Agriculture 8:540–546.
25 Klepper, R., Lockeretz, W., Commoner, B., Gertler, M., Fast, S., O'Leary, D., and Blobaum, R. 1977. Economic performance and energy intensiveness on organic and conventional farms in the Corn Belt: A preliminary comparison. American Journal of Agricultural Economics 59:1–12.
26 Lockeretz, W., Shearer, G., Klepper, R., and Sweeney, S. 1978. Field crop production on organic farms in the Midwest. Journal of Soil and Water Conservation 33:130–134.
27 Lockeretz, W., Shearer, G., and Kohl, D.H. 1981. Organic farming in the Corn Belt. Science 211:540–547.
28 Munn, D.A., Coffing, G., and Sautter, G. 1998. Response of corn, soybean and wheat crops to fertilizer and herbicides in Ohio compared with low-input production practices. American Journal of Alternative Agriculture 13:181–189.
29 Shearer, G., Kohl, D.H., Wanner, D., Kuepper, G., Sweeney, S., and Lockeretz, W. 1981. Crop production costs and returns on Midwestern organic farms: 1977 and 1978. American Journal of Agricultural Economics 63:264–269.

30 Smolik, J.D., Dobbs, T.L., and Rickerl, D.H. 1995. The relative sustainability of alternative, conventional, and reduced-till farming systems. American Journal of Alternative Agriculture 10:25–35.
31 Lockeretz, W. 1989. Problems in evaluating the economics of ecological agriculture. Agriculture, Ecosystems and Environment 27:67–75.
32 Lee, L.K. 1992. A perspective on the economic impacts of reducing agricultural chemical use. American Journal of Alternative Agriculture 7:82–88.
33 Lockeretz, W. 1991. Information requirements of reduced-chemical production methods. American Journal of Alternative Agriculture 6:97–103.
34 Dillman, D.A. 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley & Sons, New York. p. 151.
35 McCann, E., Sullivan, S., Erickson, D., and DeYoung, R. 1997. Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. Environmental Management 21:747–758.
36 Hamilton, L.C. 2003. Statistics with Stata. Wadsworth Group/ Thomson Learning, Belmont, California, USA. p. 166–170.
37 Chatterjee, S., Hadi, A.S., and Price, B. 2000. Regression Analysis by Example. 3rd ed. John Wiley & Sons, New York. p. 240–241.

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An empirical analysis of producer perceptions of traceability in organic agriculture

Edmund M. Tavernier*

Department of Agricultural Food and Resource Economics, Cook College, Rutgers University, 55 Dudley Road, New Brunswick, NJ 08901, USA.
*Corresponding author: Etavernier@aesop.rutgers.edu

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Abstract

This study assesses producer perceptions of traceability issues in organic agriculture, using survey data from the 2001 National Agricultural, Food and Public Policy Preference Survey. The survey provides food policy and socio-economic data that facilitate the examination of traceability issues in organic agriculture. The logistic regression models that are used to examine the relationship between traceability and organic agriculture are robust across models. The models indicate a decreased likelihood for federal government intervention on the part of organic producers for policies that improve traceability from consumer back to producer to improve food safety and tracking. However, the results suggest that organic producers with sales under $US 50,000 are more likely to indicate some willingness for government intervention. The analysis also shows that producers want food products made with biotechnology to be labeled if there is a scientifically determined difference in the product. While education may be an avenue to facilitate greater acceptance of traceability issues, the results indicate a negative relationship between the acceptance of traceability and farmers with a bachelor's degree. This finding is surprising given the on-going debate surrounding biotech foods and traceability. Clearly the reluctance on the part of producers with bachelor's degrees to embrace tracing could hinder such efforts if those producers assume leadership positions in their communities. Perhaps such results are a reflection of the confidence that those producers have in the quality of organic produce.

Key words: biotech foods, logistic regression, organic agriculture, traceability

Introduction

New challenges to the US food supply have raised concerns over food safety. Two of the most important challenges are the increasing number of new food pathogens and the advent of genetically modified (GM) foods. To combat these challenges, mechanisms such as traceability have received increased attention in the literature.

Several definitions of traceability exist in the literature[1]. In this study traceability is defined as a process that requires documentation tracking foods from producers to consumers. This practice is commonly followed in organic farming through extensive documentation along the food-supply chain. While it is unlikely that foods produced under such a system would be contaminated given the conditions of production in such a framework, the issue of traceability has been discussed in the context of genetically modified (GM) foods. For example, the European Commission has passed two new regulations to deal with the labeling and traceability of GM organisms[2,3]. The regulations address both food and animal feed and are intended to provide information to the consumer, to ensure transparency of GM ingredients in the food chain and to encourage the unblocking of an (unofficial) moratorium on GM crops[4].

The issue of traceability has also been driven by food safety concerns; for example, scares such as like the human form of bovine spongiform encephalopathy (mad cow disease), bioterrorism and contamination of the food supply. On December 14, 2000, for example, Cargill Corp. announced a recall of 16.7×10^6 lb (7.6×10^6 kg) of turkey and chicken products because of contamination with *Listeria*, a microbe that can cause high fever, severe headaches, neck stiffness and sometimes death. More recently, Pilgrim's Pride, the parent company of Wampler

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Foods, announced a nationwide recall of 27×10^6 lb (12.3×10^6 kg) of turkey and chicken products after tests found *Listeria* in the drain. This recent outbreak was blamed for at least 7 deaths and 39 illnesses in Pennsylvania, New Jersey and the surrounding states[5]. Traceability issues in other areas of the food supply chain are beginning to come under closer scrutiny from researchers.

Deasy[6] argues that the dairy industry is under pressure to improve product security, implement efficient risk-management and rapid-response capabilities, and manage quality 'from trough to table' to achieve full, verifiable traceability. Mousavi et al.[7] state that the meat industry is seeking to establish reassurance on traceability and production techniques that may help promote confidence in the integrity and origin of their products. Liddell and Bailey[8] demonstrate that the US pork industry lags behind its major international competitors and major international customers in terms of developing programs for traceability, transparency and assurance. In light of these concerns, baby boomers are driving the demand for food products generated by alternative agriculture practices.

The National Research Council[9] defines alternative agriculture as a system of food or fiber production that systematically pursues: (1) a more thorough incorporation of natural processes such as nutrient cycling, nitrogen fixation and beneficial pest–predator relationships into the agricultural production process; (2) reduction in the use of off-farm inputs with the greatest potential to harm the environment or the health of farmers and consumers; (3) productive use of the biological and genetic potential of plant and animal species; (4) improvement in the match between cropping patterns and the productive potential and physical limitations of agricultural lands; and (5) profitable and efficient production with emphasis on improved farm management, prevention of animal disease, optimal integration of livestock and cropping enterprises and conservation of soil, water, energy and biological resources. These goals contain the same elements that form the framework for organic agriculture.

The National Organic Standards Board defines organic agriculture as an 'ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. The system is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony'[10]. The National Organic Program (NOP) Final Rule was issued in December 2000 after a decade of deliberations, and was fully implemented on October 21, 2002. Those who grow or market organic products must comply with the rule. Under the USDA's new NOP rules, all organically labeled products must conform to nationally set standards. Products carrying the 'Organic' label must be produced without hormones, antibiotics, pesticides, synthetic fertilizers or genetic modification. The rule uses different terms to identify the levels of organic content.

For example, products carrying the '100% Organic' label cannot contain any nonorganic ingredients while products with the 'Organic' label must contain ingredients that are at least 95% organic. The 'Made With Organic Ingredients' label must contain at least 70% organic ingredients and may not contain any added sulfites[11]. Govindasamy et al.[12] find that the use of labels to identify products as certified organic has a positive effect on increasing sales from organic production and on the number of farmers being satisfied with their returns from organic production.

While labeling provides valuable information for consumers wishing to avoid nonorganic products, it says little about the tracking mechanism of food products from producer to consumer. Whether such tracking is even necessary in an organic production food framework is an empirical question. Moreover, government agencies have introduced the science-based food safety program—Hazard Analysis and Critical Control Point (HACCP)—to address new challenges to the food supply such as *Escherichia coli* and *Salmonella enteritidis*[13]. Further studies are also currently being undertaken to develop Organic HACCP recommendations for improved procedures for securing consumer-oriented food quality of certified organic foods from 'plough to plate'[14]. These studies will likely augment a Food and Agriculture Organization report that concludes that organic farming potentially reduces the risk of *E. coli* infection[15]. Given the concerns about food safety, research examining traceability issues in organic agriculture on the producer side is clearly needed to inform the debate. This paper uses New Jersey producers as a case study to inform such debate.

The paper is organized as follows. In the next section, the organic foods market is examined in some detail. This section is followed by the data source and profile of agricultural producers used in the paper. Next, the results from the empirical analysis on traceability issues in organic agriculture are presented. This section is followed by a discussion of the results.

The Organic Foods Market

The organic foods market has experienced tremendous growth in recent years. Farm sales of organic produce in the US have grown from $US 78 million in 1980 to about $US 7.8 billion in 2000[16,17]. Retail sales of organic foods in the US were projected to be $US 11 billion to $US 13 billion in 2003[18]. The increase in sales and the continued expansion of sales of organic foods are driven in part by consumer concerns for food safety, animal welfare, and the environmental and ecological impact of food production and agro-processing[19]. These concerns have led to increasing investments in farm, agri-business and food marketing in alternatively produced products, and suggest a responsiveness to the growing interest in organic foods[20]. This interest has led to a doubling of certified organic cropland in the US from 1992 to 1997 to 1.3 million acres[17], and was projected to increase to 950,000 hectares (2.3 million acres) in 2003[18]. The growing consumer demand has also led to the introduction of over 800 new organic products in the

first half of 2000 (mainly desserts) and the introduction of new organic beverage products in 1999[21].

The increased availability of organic produce in supermarkets is likely to further spur the growth of organic foods. Consumers indicate that they are more likely to buy organic produce if they are readily available in such outlets[22]. This willingness has facilitated 20% growth in organic foods per year since 1990 and has increased the availability of organic products in nearly 20,000 natural food stores and 73% of all conventional grocery stores[17]. As the growth of organic foods continues to increase, issues related to health will likely surface and traceability issues in organic foods may assume greater prominence. For example, the main criterion for organic acceptability of materials in organic management is that natural materials are allowed and synthetic materials are prohibited[23]. Thus meat, poultry and dairy labeled organic must come from creatures that are raised on organic grains and grasses, given access to the outdoors and fed no growth hormones or antibiotics.

Data Source and Producer Profile

The data for this study were obtained from the Agricultural, Food, and Public Policy Preference Survey conducted in May 2001[24]. The study was undertaken to provide input in the 2002 Farm Bill process since The Federal Agricultural Improvement and Reform Act of 1996, which contains language authorizing federal farm programs, expired in 2002. The mail-only survey was supported by the National Public Policy Education Committee, comprised of faculty from land grant universities, Farm Foundation and statisticians from each state's agricultural statistics service. Each state surveyed producers, using a questionnaire composed of national questions, selected optional questions and state-specific questions. The National Agricultural Statistics Service was responsible for the selection of the sample, printing and mailing of the questionnaires, and telephone follow-up and data-collection activities. The data-collection effort consisted of first and second mailings of questionnaires. The questionnaires were sent to Kansas State University for data entry and aggregate analysis.

Twenty-seven states, including New Jersey, participated in the national survey. The New Jersey part of the national effort began in April 2001. During that month, a master survey consisting of questions to be asked of agricultural producers in all participating states was sent to Rutgers University from Kansas State University with the opportunity to include state-specific questions. Questions were sought from the agricultural community and persons associated with that community, such as Agricultural Agents and Agricultural Specialists. Their input was incorporated in the survey.

The New Jersey Agricultural Statistics Service chose a random sample of 631 farmers for participation in the survey. One hundred and forty-four of the surveys were returned, giving a response rate of 23%. This rate matches the average response rate for the northeast, and is above the national response rate of 20%. The participating states in the northeast include Maryland, New York, Pennsylvania and New Jersey.

Table 1 presents summary statistics for demographic and structural variables of the 102 observations used in the study. The demographic variables are education and sales, while the structural variables are organic agriculture, biotechnology, animal waste and traceability.

The *demographic variables* are defined as follows.

- Education: represents the last year of school completed by the principal operator.
- Sales: represent annual gross sales.

The *structural variables* are defined as follows.

- Organic agriculture is a priority area identified by farmers for research and extension education in the northeast. The analysis proceeds on the assumption that if farmers identify organic agriculture as a priority area for research and extension education, they are more likely to be engaged in, or are already engaged in, alternative agricultural practices. This variable is used as a proxy for organic agriculture producers.
- Animal waste represents the provision of financial incentives by the federal government to facilitate the management of animal waste.
- Biotechnology represents the labeling of food products when there is a scientifically determined difference in the product.
- Traceability represents the role of the federal government in increasing efforts to improve traceability.

Table 1. Summary statistics of selected variables used in the study.

Variable	Mean	Standard deviation
Demographic characteristics		
Education		
Some college	0.245	0.430
Bachelor's degree	0.294	0.456
Advanced degree	0.206	0.404
Sales		
Under $US 10,000	0.461	0.498
$US 10,000–49,999	0.245	0.430
$US 50,000–99,999	0.088	0.284
Structural characteristics		
Organic agriculture	0.412	0.492
Biotechnology	0.90	0.297
Animal waste	0.657	0.475
Traceability	0.775	0.418
Interaction variables		
Organic × sales under $US 10,000	0.186	0.39
Organic × sales $US 10,000–49,999	0.088	0.49
Organic × sales $US 50,000–99,999	0.039	0.20
Number of observations equal	102	

The demographic variable with the highest mean is the number of farmers indicating that their annual gross sales from farming in recent years, including government program benefits, is less than $US 10,000. The mean value of that variable is 0.46, which, because of the construction of the variable, may also be interpreted as a percentage. Thus 46% of farmers receive less than $US 10,000 from farm sales. Twenty-five percent and 9% of the producers have annual gross sales of $US 10,000–49,999 and $US 50,000–99,999, respectively.

A greater percentage of respondents have a bachelor's degree than any other educational qualification. The mean of respondents with a bachelor's degree is 0.29, compared to 0.21 of respondents indicating that they have an advanced degree. Taken together, Table 1 suggests that 75% of respondents have some type of college education.

The traceability variable has a mean of 0.78 in the structural variables. Thus 78% of respondents would like the federal government to increase efforts to improve traceability from consumer back to producer, in an effort to improve food safety and tracking. The high percentage suggests that transitioning to a traceability environment may not be a difficult task for organic producers. This finding is important because in the alternative agricultural framework, natural materials, in particular animal waste materials, are the preferred source of materials used in organic agriculture. Perhaps it is not surprising then, that 66% of respondents would like the federal government to provide financial incentives to encourage the provision of the environmental benefits that the proper management of animal waste provides. Forty-one percent of respondents believe that organic agriculture should be a priority area for research and extension education in the northeast.

Biotechnology has the highest mean in the structural variables. Ninety percent of respondents indicate that food products made with biotechnology should be labeled if there is a scientifically determined difference in the product. This figure is unusually high considering the anecdotal evidence that suggests that US farmers are opposed to the labeling.

While the percentage of respondents answering in the affirmative may be high for certain categories, the percentage that prefers a certain action within that category may be low. For example, although 78% of respondents indicate that the federal government should increase efforts to improve traceability from consumer back to producer to improve food safety and tracking, a one-to-one mapping from organic agriculture to traceability suggests that only 26% of respondents who indicate a preference for organic agriculture also indicate such a preference for traceability (Table 2). In the sales category, most respondents who indicate a preference for alternative agriculture have annual sales of less than $US 10,000. The respondents were not asked whether they were organic food producers. However, in a recent survey, most organic producers in Pennsylvania, New York and New Jersey described themselves as small farmers[12]. In that regard there appears to be an inverse relationship between farm size, as measured by sales, and organic agriculture; i.e., the greater the sales from farming, the less likely are respondents to indicate a preference for alternative agriculture.

Table 2. Percent of respondents expressing a preference for traceability in organic agriculture, selected variables.

Variable	% of sample	% expressing preference
Demographic characteristics		
Education		
Some college	25	15
Bachelor's degree	29	15
Advance degree	21	9
Sales		
Under $US 10,000	46	19
$US 10,000–49,999	25	9
$US 50,000–99,999	9	4
Structural characteristics		
Animal waste	66	31
Biotechnology	90	37
Traceability	78	26

Results of Empirical Analysis

The analysis seeks to test the hypothesis that there exists a relationship between organic agriculture producers and traceability. The dependent variable is traceability. The variables used in the empirical analysis are defined in Table 3. The results are obtained using the logit methodology and are presented in Table 4. In addition to the results, Table 4 also presents goodness of fit measures such as the chi-square test statistic, the McFadden R^2 test statistic, and the percent of successful predictions.

The chi-square test statistic tests the null hypothesis that the coefficients of all the independent variables equal zero. The null hypothesis is rejected at the significant level 0.0001 and better, indicating that the model has significant explanatory power. The McFadden R^2 values are 0.18 and 0.32, and also indicate an extremely good fit for the estimated models[25]. This statistic is generally low in binary dependent variable models estimated with cross-section data[26]. The percent of correct predictions is also very high. This measure predicts whether or not an event will occur given a set of explanatory variables[27]. The models correctly predict 83.3% to 87.3% of the responses.

The variables included in the models are chosen for their theoretical and heuristic relationship, reported in previous studies. For example, the organic acceptability of materials requires the use of nonsynthetic materials such as animal waste. Thus the animal waste variable captures the relationship between traceability and that form of soil enhancement.

Model 1 has a significance level of 0.0001, the McFadden R^2 is 0.18 and the model correctly predicts

Table 3. Variables used in the analysis.

Traceability	1, if the producer wants the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking; 0 otherwise
Waste	1, if the producer wants the federal government to provide financial incentives to encourage the provision of environmental benefits afforded by animal waste management; 0 otherwise
Biotech	1, if the producer wants food products made with biotechnology to be labeled if there is a scientifically determined difference in the product; 0 otherwise
Organic	1, if the producer wants alternative agriculture and agricultural enhancement to be a priority area for research and extension education in the northeast; 0 otherwise
Sales10	1, if the producer has annual gross sales including government payments of under $US 10,000; 0 otherwise
Sales49	1, if the producer has annual gross sales including government payments between $US 10,000 and $US 49,999; 0 otherwise
Sales99	1, if the producer has annual gross sales including government payments between $US 50,000 and $US 99,999; 0 otherwise
College	1, if the producer has some college education; 0 otherwise
BA	1, if the producer has college bachelor's degree; 0 otherwise
MA	1, if the producer has college advanced degree; 0 otherwise

Table 4. Logistic regression results of the determinants of traceability in organic agriculture.

Variable	Model 1	*P*	Model 2	*P*	Model 3	*P*
Intercept	–0.5131 (0.658)		–0.5521 (0.346)		1.4633 (1.019)	
Waste	1.2294 (2.137)*	0.18	1.5418 (2.317)**	0.18	1.5093 (2.303)**	0.18
Biotech	2.1867 (2.793)**	0.32	2.3312 (2.262)**	0.27	1.8474 (2.079)**	0.22
Organic	–1.7805 (3.017)**	–0.26	–1.6886 (2.622)**	–0.20	–3.6061 (3.453)**	–0.43
Sales10			1.6225 (2.034)*	0.19		
Sales49			2.3808 (2.333)**	0.28		
Sales99			0.9705 (0.863)			
College			–1.6450 (1.352)		–1.8636 (1.508)	
BA			–2.3501 (2.032)*	–0.28	–2.6632 (2.196)**	–0.32
MA			–1.5908 (1.229)		–1.7455 (1.337)	
Organic × Sales10					2.2593 (2.048)**	0.27
Organic × Sales49					3.2529 (2.465)**	0.39
Organic × Sales99					2.2279 (1.450)	
Sample size	102		102		102	
McFadden R^2	0.18		0.31		0.32	
Chi-squared$_{df}$	20.04_3		34.23_9		35.03_9	
Significance level	0.0001		0.0000		0.0000	
Correct prediction (%)	83.3		87.3		86.3	

Absolute values of *t*-statistics are in parenthesis.
**and * indicate significance at the 1% and 5% level, respectively.

83.3% of the responses. The estimated coefficients are all significant at the 5% level or better. There is a negative relationship between traceability and organic agriculture and a positive relationship between traceability and waste and biotech. In the case of organic agriculture, the results suggest that producers who view organic agriculture as a high priority area for research and extension are 26% less likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking.

With respect to biotechnology, the results of this research suggest that producers who want food products made with biotechnology to be labeled if there is a scientifically determined difference in the product are 32% more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking.

With respect to the animal waste variable, the results suggest that producers who want the federal government to provide financial incentives to encourage the provision of the environmental benefits afforded by the management of animal waste are 18% more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. This result appears contradictory when one

considers the negative relationship between organic agriculture and traceability. However, producers, while cognizant of the absence of pesticides on organic produce may be concerned about possible pathogens in animal waste.

Model 2 incorporates the structural variables with socio-economic and demographic characteristics. The model has a significance level of 0.00001, the McFadden R^2 is 0.31 and the model correctly predicts 87.3% of the responses. The structural variables are robust across models 1 and 2, and there are statistically significant coefficients in the sales and education categories.

The results suggest that there exists a positive relationship between farmers whose gross sales are less than $US 10,000 and farmers whose gross sales are between $US 10,000 and $US 49,999, and traceability. The analysis indicates that farmers with gross sales of less than $US 10,000 are 19% more likely to indicate that the federal government should increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. Farmers whose gross sales are between $US 10,000 and $US 49,999 are 28% more likely to indicate that the federal government should increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. The variable that measures farmers with sales between $US 50,000 and $US 99,999 is not significant.

In the education category, the results suggest that producers with a bachelor's degree are 28% less likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. This finding may reflect a level of confidence, regarding the absence of chemicals in organic produce, on the part of such producers.

The results from model 2 seem to suggest that farm size, in terms of sales, matters in one's perception regarding whether the federal government should increase efforts to improve traceability. However, the model does not address whether 'organic' producers with small farms are more likely to indicate a preference for traceability. To address that issue, interaction variables were created between the sales and organic agriculture variables. The results of that analysis are presented in model 3.

Model 3 has a significance level of 0.00001, the McFadden R^2 is 0.32 and the model correctly predicts 86.3% of the responses. The structural variables are robust across the three models and the education variable is robust across Models 2 and 3. The results suggest that 'organic producers' with annual sales under $US 10,000 are 27% more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. However 'organic producers' with sales between $US 10,000 and $US 49,999 are 39% more likely to indicate such a preference.

Discussion

Logistic regression models are used to examine the relationship between traceability and organic agriculture. The coefficient of organic agriculture is robust and significant at the 1% level across the models and indicates that organic producers are less likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. This result may be a reflection of the belief that organic food products are healthier than products grown from conventional agriculture. Sixty-six percent of consumers in a Hartman Group survey cited health as a 'top motivator' for purchasing organic products[28]. However, the USDA organic label does not imply that organic foods are safer or better than other kinds of food.

The results suggest that organic producers with sales under $US 50,000 are more likely to indicate willingness for such a preference and illustrate the importance of examining organic producers of different farm-size categories when addressing issues of traceability. This finding is particularly important because the arguments on both sides of the traceability issue have been driven primarily by the food safety concerns of consumers and have largely ignored the perceptions of producers. The perceptions are important for they provide information that may help guide an education campaign on organic agriculture.

In addition to organic agriculture, the analysis provides producer perceptions on the relationship between animal waste management, biotechnology, sales and education on traceability. The results suggest that producers who want the federal government to provide financial incentives to foster the environmental benefits of animal waste are more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. This finding is robust and significant at the 5% level across the models. Whether this finding is a recognition on the part of producers that animal waste may contain deadly pathogens is not clear. However, the analysis indicates that producers who want the federal government to provide financial incentives to foster the environmental benefits of animal waste are 18% more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking.

The labeling of foods containing biotechnology has generated significant debate. Michael J. Phillips, executive director for food and agriculture at the Biotechnology Industry Organization argues that the labeling of biotech foods is not only unnecessary, it would actually confuse consumers who might think that the process of biotechnology might, of itself, have an impact on food safety[29]. Oregon's Measure 27, which would require the labeling of all foods and food additives that have been genetically engineered, was defeated by over 70% of Oregon's voters in November 2002[30]. While the debate continues, the uncertainty surrounding issues of biotechnology are

perhaps captured in the willingness of producers to have biotech products tracked. Such a position seems to converge with that of consumers, who have expressed some willingness for such a preference[31]. The analysis indicates that producers who want food products made with biotechnology to be labeled if there is a scientifically determined difference in the product are more likely to want the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking. This finding may help insulate producers from the charge, by consumers, of indifference regarding issues of biotechnology.

While organic producers with sales under $US 50,000 are more likely to indicate a willingness for the federal government to increase efforts to improve traceability from consumer back to producer to improve food safety and tracking, organic producers, overall, indicate a differing preference. The results do lend support to earlier findings that organic producers are likely to be small farmers, and may signal a divergence between small and large farmers, that is farmers with sales in excess of $US 50,000, with respect to traceability and organic agriculture. This divergence may create increased difficulty for greater acceptability on traceability issues in organic agriculture if large farms, which invariably have the most resources, are 'not on board' the move to such efforts.

One avenue that could facilitate greater acceptability of traceability issues is education. However, the results indicate a negative relationship between traceability and farmers with a bachelor's degree. This finding is surprising, given the ongoing debate surrounding biotech foods and traceability. Clearly, the reluctance on the part of producers with bachelor's degrees to embrace tracking could hinder such efforts if those producers assume leadership positions in their communities. Perhaps the results are a reflection of the confidence that such producers have in the quality of organic produce. Whether the organic-food-producing sector continues to enjoy that status and its significant growth may hinge on continuing to assure consumers of the wholesomeness of organic foods. Traceability affords one avenue to achieve that goal, and the results suggest that small organic producers are willing to embrace the concept.

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References

1 Available at Web site http://www.agbioforum.org/v5n2/v5n2a01-smyth.htm (verified 2 December 2003).
2 Available at Web site http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_268/l_26820031018en00010023.pdf (verified 2 December 2003).
3 Available at EChttp://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_268/l_26820031018en00240028.pdf (verified 2 December 2003).
4 Schofield, G. 2002. EU regulation of genetically modified organisms: food and feed, traceability and labeling. Journal of Commercial Biotechnology 9:27–30.
5 The Star Ledger 2002. Listeria found in N.J. firm forces recall. 3 November. p. 9.
6 Deasy, D.J. 2002. Food safety and assurance: the role of information technology. International Journal of Dairy Technology 55:1–4.
7 Mousavi, A., Sarhadi, M., Lenk, A., and Fawcett S. 2002. Tracking and traceability in the meat-processing industry: a solution. British Food Journal 104:7–19.
8 Liddell, S. and Bailey, D. 2001. Market opportunities and threats to the U.S. pork industry posed by traceability systems. The International Food and Agribusiness Management Review 4:287–302.
9 National Research Council 1989. Alternative Agriculture. National Academy Press, Washington, DC, USA.
10 USDA. Available at Web site http://www.nal.usda.gov/afsic/ofp/ (verified 5 November 2002).
11 AMS 2000. National Organic Program: Labeling – Preamble, Subpart D – labels, Labeling, and Market Information. Available at Web site http://www.ams.usda.gov/nop/Nop/standards/LabelPre.html (verified 4 November 2002).
12 Govindasamy, R., Italia, J., DeCongelio, M., Anderson, K., and Barbour, B. 2000. Empirically evaluating grower characteristics and satisfaction with organic production. New Jersey Agricultural Experiment Station Report P–02139–1–00 May.
13 FDA 2001. HACCP: A state-of-the-art approach to food safety. Available at Web site http://www.cfsan.fda.gov/~lrd/bghaccp.html (verified 15 July 2003).
14 Cordis 2003. Available at Web site http://dbs.cordis.lu/cordis-cgi/srchidadb?ACTION=D&SESSION=213942003–6–10&DOC=2&TBL=EN_PROJ&RCN=EP_RCN:69966&CALLER=EISIMPLE_EN_PROJ (verified 15 July 2003).
15 FAO 2000. Food safety and quality as affected by organic farming. Available at http://www.fao.org/docrep/meeting/X4983e.htm (verified 15 July 2003).
16 Butler, J.L. 2002. The economics of organic milk production in California: a comparison with conventional costs. American Journal of Alternative Agriculture 17:83–91.
17 Dimitri, C. and Greene, C. 2002. Recent growth patterns in the U.S. organic foods market. Available at http://www.ers.usda.gov/publications/aib777/aib777a.pdf (verified 4 November 2002).
18 Yussefi, M. and Willer, H. (eds) 2003. The World of Organic Agriculture 2003 – Statistics and Future Prospects. Available at Web site http://www.soel.de/inhalte/publikationen/s/s_74.pd (verified 15 July 2003).
19 Opara, L.U. and Mazaud, F. 2001. Food traceability from field to plate. Outlook on Agriculture 30:239–247.
20 Kistoff, B. 1998. Emergence of U.S. organic agriculture – Can we compete? [discussion], American Journal of Agricultural Economics 80:1130–1133.
21 Myers, S. and Rorie, S. 2000. Facts and stats: The year in review. Organic and Natural News, December.
22 Govindasamy, R., DeCongelio, M., Italia, J., Barbour, B., and Anderson, K. 2001. Empirically evaluating consumer characteristics and satisfaction with organic produce. New Jersey Agricultural Experiment Station Report P–02139–1–01 May.
23 Fetter, T.R. and Caswell, J.A. 2002. Variations in organic standards prior to the National Organic Program. American Journal of Alternative Agriculture 17:55–74.

24 Lubben, B.D., Simons, C.J., Bills, N.L., Meyer, N.L., and Novak, J.L. 2001. The 2002 Farm Bill: US Producer Preferences for Agricultural, Food, and Public Policy. Farm Foundation, National Public Policy Education Committee, September, Kansas State University, USA.
25 Bell, C.D., Roberts, R.K., English, B.C., and Park, W.M. 1994. A logit analysis of participation in Tennessee's forest stewardship program. Journal of Agricultural and Applied Economics 26:463–472.
26 Pindyck, R. and Rubinfeld, D. 1991. Econometric Modes and Economic Forecasts. McGraw Hill, New York, USA.
27 Judge, G., Canterhill, R., Griffiths, W.E., Lutkepohl, H., and Lee, T.C. 1982. Introduction to the Theory and Practice of Econometrics. John Wiley and Sons, New York, USA.
28 Newsweek 2002. Certified organic. 30 September. p. 50–55.
29 Business Week 1999. Warning: Biotech is hurting itself. 20 December.
30 Betterfoods 2002. Available at Web site www.Betterfoods.org/News/News.htm (verified 6 December 2002).
31 Business Week 2002. GM Foods: Why fight labeling. 11 November.

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Watershed-scale modeling of the water quality effects of cropland conversion to short-rotation woody crops

Karen Updegraff[1,*], Prasanna Gowda[2] and David J. Mulla[2]

[1]South Dakota School of Mines and Technology, Institute of Atmospheric Sciences, 501 E. St. Joseph St., Rapid City, SD 57701, USA.
[2]University of Minnesota, Department of Soil, Water and Climate, 1991 Upper Buford Circle, St. Paul, MN 55108, USA.
*Corresponding author: Karen.Updegraff@sdsmt.edu

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Abstract

The conversion of cropland to the production of woody biomass, or short-rotation woody crops (SRWCs), has the potential to provide an economic alternative to Midwestern farmers, while simultaneously offering an environmental dividend in the form of reduced erosion and nutrient pollution of streams. However, notwithstanding a wealth of plot-scale and anecdotal data suggestive of these benefits, there are few watershed-scale integrated analyses on which to base regional policy decisions regarding incentives to convert fields to SRWCs. This study applied a field-scale runoff, sediment and nutrient transport model (Agricultural Drainage and Pesticide Transport, ADAPT) to a simulation of 10, 20 and 30% cropland conversion to SRWCs, grown on a 5-year rotation, in a representative Minnesota River sub-watershed. While the generation of a highly precise simulation would require extensive calibration of the model, its application with parameters previously calibrated to neighboring, similar watersheds provided reasonably robust results that indicated real differences resulting from cropland conversion. At the highest conversion level, mean annual runoff was reduced by up to 9%, sediment loads by 28% and nitrogen (N) loads by 15%, although total phosphorus (P) loads increased by 2% relative to the no-SRWC scenario. However, the relative benefits of conversion at the field level were contingent on soil type, drainage status and the alternative crop. These differences provide useful insights with respect to the targeting of possible conversion incentives.

Key words: ADAPT, nitrate, sediment, short-rotation woody crops, watershed models

Introduction

Short-rotation woody crop (SRWC) production systems have been the focus of much recent research, both because of their commercial potential and because of the perceived environmental dividend compared to conventional cropping systems. The production of biomass crops has the potential to provide an economic alternative for farmers faced with low prices for row crops. Biomass crops and residues already constitute the most significant proportion of the US renewable energy supply, and woody biomass crops may provide a feasible alternative source of fiber for an evolving forest products industry. Perennial cropping systems also tend to perform much better than annual crops with respect to nutrient sequestration and soil stabilization. These benefits have been cited as justification for some degree of public investment, in the form of subsidies or incentives to farmers, to reduce private risk and to encourage cropland conversion to trees[1].

Potential reductions in erosion and agricultural runoff, with commensurate improvements in surface water quality, are important considerations in most US cropland conservation programs, including the Conservation Reserve Program (CRP) and the Environmental Quality Incentives Program (EQIP). Excessive sediment loads can lead to high water-treatment costs and large expenditures on culvert, ditch and reservoir maintenance. The positive economic impact of water-quality improvement on recreational values has been documented extensively[2–5].

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Systematic evaluations of the environmental and social benefits of cropland conversion to SRWCs have been constrained by the relative novelty of SRWC systems, which represent a synthesis of farming and forestry. A number of relevant regional- or national-scale modeling and valuation exercises have been conducted to assess the water-quality impacts of the CRP[6,7]. The information resulting from these studies has generally been too broad in scope to be useful for region-specific policy development.

Because of the prominence of surface water quality as an environmental issue in the Minnesota River Basin, which is heavily agricultural, the sediment and nutrient loading effects of converting land in row crops to trees are of immediate concern to policy makers. Field- and plot-scale studies of trees planted in cropland with and without cover crops have demonstrated reductions in sediment and nutrient delivery to streams, ranging from nonsignificant to as much as 64%[8,9].

However, there are few watershed-scale integrated evaluations of this effect. Notable exceptions include a study by Licht[10], who reported a 69% reduction in NO_3-N losses based on a paired-watershed comparison of in-field and riparian tree plantings with conventional crops in Iowa. In a study comparing conventional corn with agroforestry (oak, *Quercus* spp.) and contour grass strips, initial measurements indicated that the grass strips retained about 18% more nutrients and sediment than the (widely spaced) trees[11]. The data emerging from these studies are as yet too limited and site-specific to serve as a basis for policy decisions.

The study described in this paper was part of a broader analysis of the environmental impact of cropland conversion to hybrid poplar (*Populus* spp.) SRWCs. Its objective was to provide data that were geographically specific but also generalized enough to be scalable to the river-basin level, thereby constituting a policy-relevant analysis with respect to a major farming region of Minnesota. This report will focus on the watershed-scale modeling of cropland conversion to SRWCs, and the water-quality predictions that resulted from it.

Methods

Watershed location

The High Island Creek (HIC) watershed is one of the few rural sub-watersheds of the Lower Minnesota River in southern Minnesota (44°N, 94°W). High Island Creek, a second-order stream, and its major tributary, Buffalo Creek, are 91 and 25 km long, respectively. The topography of the watershed is mostly flat to gently rolling, but the eastern portion consists of steep hills and bluffs bordering the Minnesota River Valley. Nearly 85% of the 62,023-ha watershed is in row crops (corn, soybeans, small grains and forage), with an additional 5% in pasture or hay, 5% forested, 3% urban and 2.5% water or wetland[12]. An estimated 49% of the cropland has tile drainage installed[13]. The 1998 MN 305(b) Assessment of Stream Water Quality rated most of HIC as 'threatened' or 'partially supporting' with respect to support of aquatic life and various indicators, including oxygen depletion, turbidity, habitat alteration and bacteria[14]. Seven lakes in the HIC watershed have some type of public access. The two for which lake water-quality data were available from the Minnesota Pollution Control Agency (MPCA) were classified as 'non-supporting' with respect to swimming, although all lakes support some level of fishing.

Watershed modeling

The ADAPT (Agricultural Drainage and Pesticide Transport) model[15] is a field-scale water-table management model that was developed by enhancing GLEAMS[16], a root-zone water-quality model, with the subsurface drainage algorithms from DRAINMOD, a subsurface drainage and deep seepage model[17]. Its consequent ability to predict tile drainage contributions to runoff, nutrient and pesticide loads make it particularly valuable in the midwestern US, where nearly 30% of agricultural land has been modified by drainage[18]. Watershed-scale methodology and water-routing algorithms were developed by Gowda et al.[19]. The model is comprised of hydrology, erosion, nutrient and pesticide modules. The hydrology component simulates major surface and subsurface hydrologic processes, including snowmelt, infiltration, surface runoff, evapotranspiration, subsurface drainage, subirrigation and deep seepage. Model outputs included total runoff and loadings of sediment, nutrients and pesticides on daily, monthly or annual timesteps.

Model input. Climatic inputs to the ADAPT model included daily precipitation, temperature, humidity, wind velocity and solar radiation data for the simulation period (1996–2000). The 5-year period was selected to evaluate the water-quality impacts of a complete rotation of hybrid poplar, as proposed for a biomass power project near St. Peter, MN[20]. Precipitation data were obtained from four stations dispersed around the watershed. In the model simulation, a simple median precipitation value was used as it gave better runoff predictions during initial tests than simple average or Theissen polygon methods[13].

Generalized agricultural management data[21–24] were incorporated into crop data files originally developed by Dalzell[13]. These included crop rotations for corn, soybeans and wheat, planting and harvesting dates, tillage and fertilizer operations. Parameter files were also provided for noncrop land uses, such as pasture, forest and urban development.

Plant growth parameters for hybrid poplar, such as seasonal changes in leaf area index (LAI), rooting depth, biomass accumulation and carbon:nitrogen (C:N) and nitrogen:phosphorus (N:P) ratios were generalized from an extensive literature on poplar growth physiology, largely from the North Central region of the US[25–29]. Leaf litter returns to the soil were simulated by adjusting the model's yield ratio parameter.

Management parameters for hybrid poplar were based on local guidelines for farm-scale production of hybrid poplar in Minnesota[30]. Model parameters assumed fall tillage (including an application of glyphosate), with further tillage and planting the following spring. Weed control included herbicide applications in the spring of the first 3 years, and mechanical weed control (rotary hoe tillage) seven times in the first year and twice in the second and third years. N fertilizer was applied at a rate of 168 kg N ha^{-1} in the third year. Tillage and fertilizer inputs for conventional crops and hybrid poplar are compared in Table 1.

The ADAPT runoff routing module operates on hydrologic response units (HRUs), which are hydrologically unique polygons composed of geographically indexed overlays of soil type, land use, slope, crop and tillage information. The HIC watershed includes four STATSGO (State Soil Geographic Database) soil map units (Table 2), with average slope ranging from 3 to 17% and in texture classes from fine argillic to sandy. Identical HRUs were aggregated to form transformed HRUs, or THRUs. It should be noted that THRUs do not retain the positional information initially present in the HRUs. This data arrangement is based on the assumption that the time of concentration in the study watershed is less than 24 h, the time-step resolution of the model. This assumption is valid for the HIC watershed. Geographic information system (GIS) overlay analysis of land use, tillage, soil and slope layers for the HIC watershed resulted in 36 THRUs.

Table 1. Management inputs for major cropping systems included in the simulation, summed over the 5-year SRWC rotation. The first 'priming' year of the simulation has no SRWCs and is excluded.

Crop rotation[1]	Number of tillage operations	Fertilizer (kg NO_3/NH_4 ha^{-1})
Conventional tillage		
Corn	15	644.3
Wheat	15	382.7
Corn/soy/corn	15	424.3
Soy/corn/soy	15	299.8
SRWC[2]	11	168.0
Reduced tillage		
Corn	10	644.3
Wheat	10	382.7
Corn/soy/corn	10	424.3
Soy/corn/soy	10	299.8
SRWC	1	168.0

[1] Corn and soybean rotations are simulated separately, as: 'corn/soy/corn' indicates that the rotation begins with corn, while 'soy/corn/soy' indicates that it begins with soybeans.
[2] SRWC, short-rotation woody crop.

Cropland conversion to SRWCs was simulated at rates of approximately 10, 20 and 30% (4665, 9664 and 14,645 ha) of the base-case cropland area, respectively. We assumed that less productive and more erosive (higher slope) HRUs were the most likely to be taken out of crop production. Similarly, conventionally tilled HRUs were converted by preference over HRUs already in conservation tillage, in order to avoid increasing erosion rates. No pasture, grass or forested land was converted to SRWCs.

In the absence of information with respect to the spatial distribution of tile drainage, THRUs were assigned to the drained or undrained categories with reference to the STATSGO cropland ratings (see Table 2). For example, all THRUs of the Lester-Hawick-Terril (LHT) soil group were assumed undrained, as these soils are coarser and more sloping than the other soil groups in the watershed. Further, it was considered most likely that higher-value cropland (rated 'prime') would have drainage installed. No drained THRUs were converted to SRWCs except at the 30% conversion level. The final distribution of THRUs for each simulation was such that 49% of the THRUs were always classified as 'drained', in conformance with the 49% drainage rate estimated for this watershed. ADAPT apportions runoff differently if drainage is present. Therefore the model is run independently for drained and undrained THRUs, and the results are summed to determine the watershed response at the outlet.

The simulation was run for 6 years, with the first year serving to 'prime' the model and allow site preparation impacts to be included. Fall site preparation impacts were assumed to manifest as sediment delivered during the second year of the simulation.

Graphic analyses and *t*-tests for differences between means were performed in the package R[31].

Results and Discussion

Notwithstanding substantial inter-annual variability in modeled runoff and loading levels, ADAPT consistently simulated end-of-rotation reductions in sediment and nitrogen loadings—both at the field-scale and at the

Table 2. Descriptive data for STATSGO soil map units in the High Island Creek watershed.

Abbreviation	Series	Mean slope	Texture range
CNG	Canisteo-Nicollet-Glencoe	0.031	Fine loamy–sandy
LCC	Lester-Cordova-Canisteo	0.040	Fine argillic–sandy
CMC	Chaska-Minneiska-Colo	0.069	Fine silty–coarse loamy
LHT	Lester-Hawick-Terril	0.170	Fine loamy–sandy

Table 3. Percent change in annual runoff and nutrient yield compared to the default (no short-rotation woody crops, SRWC) cropping configuration. Negative values indicate a decrease compared to the default. The actual modeled values for the default simulation are presented for context.

Year	Runoff ($m^3 \times 10^6$)	Sediment (Mg)	Nitrogen (Mg)	Phosphorus (Mg)
Default yield and loading values				
1996	62	18677	198	122
1997	107	47582	307	326
1998	64	4551	33	55
1999	101	4983	39	46
2000	56	5202	39	33
Mean	78	16199	123	116
Percent change from default				
10% Conversion				
1996	–1.5	–21.8	–3.9	0.2
1997	–3.6	–44.1	–15.3	–0.4
1998	6.9	–19.7	4.3	–1.9
1999	–5.9	13.0	–1.2	21.8
2000	–13.1	1.7	–7.4	7.9
Mean	–3.4	–14.2	–4.7	5.5
20% Conversion				
1996	–3.6	–25.5	–3.3	1.4
1997	–6.5	–56.2	–26.8	–0.4
1998	18.2	–19.3	12.3	0.9
1999	–16.6	–2.9	–19.9	29.1
2000	–29.0	–13.2	–25.5	5.2
Mean	–7.5	–23.4	–12.6	6.9
30% Conversion				
1996	–5.6	–26.9	–8.1	2.7
1997	–15.1	–65.1	–35.4	–7.6
1998	12.8	–26.6	3.3	–10.4
1999	–8.7	–4.9	–22.5	17.4
2000	–28.4	–17.8	–12.4	9.5
Mean	–9.0	–28.2	–15.0	2.3

watershed scale—resulting from conversion of cropland to SRWCs. This was not true with respect to phosphorus loading. The magnitude of these reductions grew as increasing proportions of cropland were converted to SRWCs (Table 3).

Model validation

Flow predictions were compared with long-term stream monitoring data collected by the US Geologic Survey (USGS)[32].

Deviations of modeled annual flow values (which averaged 77.8 million m^3) from annual USGS flow estimates (average 87.4 million m^3) ranged from 6 to 292%, with the latter high value occurring in 2000, an unusually dry year. High Island Creek in its lower reaches passes over coarse streambed sediments that effectively result in subsurface flow during dry periods (see documentation of subsurface flow in the Minnesota River passing over similar sediments just upstream of its confluence with High Island Creek[33]). This effect likely skews the flow-monitoring data. Average deviation from measured annual flows, excluding 2000, was 13%. ADAPT underpredicted total annual flows in 1995–1998 and overpredicted in 1999–2000.

Excluding the subsurface flow issue, the largest deviation in the annual flow predictions from observed data is partly due to the lack of spatial variability in modeled precipitation across the watershed. In the Minnesota River Basin, the intensity of precipitation usually varies from west to east and a single median precipitation value, based on four stations scattered over the watershed, may not have captured extreme events that occurred, for example, in 2000. Monthly observed precipitation values from four dispersed stations deviated by 69–97%, on average, from the median value over the 1997–2000 period. An area-weighted averaging method (such as the Thiessen polygon approach), might have achieved a better approximation of watershed-wide rainfall, given the apparent strong precipitation gradient across the watershed and the nonuniform distribution of gauge stations. Initial comparisons of median and Thiessen-weighted average values did not suggest that the latter method would substantially improve flow predictions, but these comparisons were not made for all years of the simulation.

When the median precipitation values supplied to the model are superimposed on plots of total monthly runoff generated by ADAPT and measured by the USGS at Henderson (Fig. 1), it is clear that the modeled runoff conforms more closely to modeled rainfall than do the observed trends, supporting the proposition that rainfall variability is largely responsible for the observed disagreements between modeled and measured runoff. Because the model appeared to respond as expected to its climatic data inputs, its performance was judged adequate for the current application, in which we were interested in relative differences rather than absolute amounts. Previous calibrations of the ADAPT model for the neighboring similar watersheds, such as Sand Creek and Bevens Creek, determined that its performance criteria with respect to flow, nitrate and sediment predictions were comparable to those of other similar models[13,34]. The model performed the most poorly during periods of high rainfall variability, and also with respect to the prediction of sediment loads when streambank erosion was an important factor.

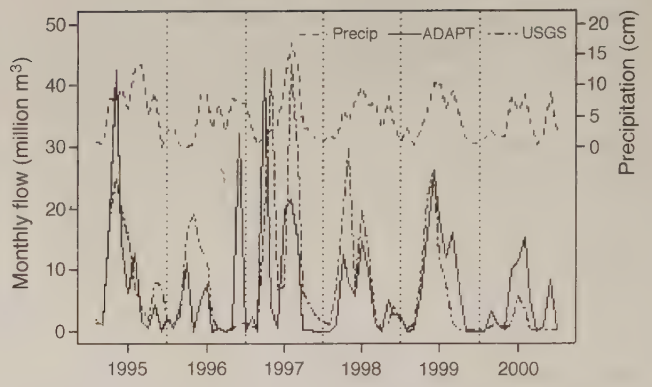

Figure 1. Monthly runoff values, with monthly precipitation superimposed, measured by the USGS at Henderson and modeled by the Agricultural Drainage and Pesticide Transport model (ADAPT). The largest absolute deviations occurred in 1997 and 1998, and are largely due to early and mid-season underpredictions by ADAPT, possibly in response to extreme events not captured by the median precipitation data (see discussion in text).

Sensitivity to parameter values

Rooting depth, productivity and fertilizer parameters were varied by ±50% to assess their effect on field-level nutrient and sediment delivery. These tests were conducted almost exclusively with respect to the SRWC THRUs, rather than for conventional crops.

While the greater rooting depth of SRWCs supposedly provides an advantage over annual crops with respect to N uptake[35], nutrient and sediment yields both proved insensitive to variations in a rooting depth parameter. This may reflect imperfections in model simulations of perennial root development (with progressive increases in root biomass) rather than an actual insensitivity to rooting depth.

The effect of differing productivity levels was tested by varying LAI curve parameterizations. However, there was no consistent correlation between modeled productivity and nutrient uptake by the crop and modeled losses to runoff and drainage. ADAPT is fairly limited with respect to its ability to simulate perennial crop growth and biomass accretion. Better simulation of these phenomena would likely have resulted in larger differences between the annual and perennial crop simulations. As it is, the observed reductions in sediment and nitrate loading most likely result simply from the reduced soil disturbance, absent annual tillage, and the greater (defined) biomass and cover of the tree crop. Levels and timing of fertilizer application can be important controls of nutrient losses from crops. Tests of 50% of the default level of N application reduced N export by 8–24% on drained THRUs and by 0.1–12% on undrained THRUs, while doubling N application rates increased N export by 16–34% on drained and by 2–18% percent on undrained THRUs. The sensitivity to N-fertilizer application rates and timing is not unique to tree crops (see Dalzell[13]), and merely serves to highlight the importance of careful fertilizer management to minimize the potential for nutrient losses in runoff.

Field-level effects of crop system, soil and drainage

Annual model outputs for each THRU were examined to assess the specific impacts of soil, crop and management inputs (Table 4). The SRWC rotation produced by far the lowest amounts of sediment per unit area of both drained and undrained cropland, compared to annual crops, on all soil groups. Results with respect to nutrient export were contingent on crop and drainage category.

Conservation tillage management reduced sediment and nutrient yields for all crops. In general, the benefits of converting conventionally tilled cropland to SRWCs were more marked than those gained from converting reduced-tillage cropland. While no-till management is not generally recommended for farm-scale SRWC systems, due to its productivity costs, we simulated a no-till system for the SRWC rotation in order to have a more complete assessment of tillage effects. Eliminating weed-control tillage operations and adjusting the USLE C-factors to reflect grass cover reduced modeled sediment yields by up to 85% relative to the conventional system, while P yields fell by 93%. In split-plot SRWC experiments in Alabama, Malik et al.[9] recorded a 64% reduction in sediment loss from tree plots two seasons after planting a rye grass cover, relative to plots with no cover crop. Because at the THRU level ADAPT models at the field scale, the modeled sediment loss values should be fairly comparable to measured plot-level values (i.e., not accounting for actual sediment delivery to the stream). Dissolved N yields were not sensitive to tillage.

The benefits of conversion also varied depending on soil type. For example, switching from conventional corn to

SRWC reduced total sediment yield by 92% on drained CNG soils, but only by 84% on CMC soils (Fig. 2). A similar switch on drained CMC fields reduced P yield by 81%, compared to an increase of 32% on LCC soils (Table 4).

The presence of subsurface drainage generally reduced modeled sediment losses attributable to overland runoff, but increased soluble nutrient (mainly NO_3-N) losses from fields. Consequently, modeled reductions in sediment yield (under SRWC) tended to be higher on drained land, while average modeled reductions in P yield were generally more substantial on undrained croplands. However, the difference in NO_3-N losses between corn and SRWC was similar on drained and undrained cropland; in fact the undrained

Table 4. Comparative modeled 5-year total nutrient and sediment yield for different transformed hydrologic response units (THRUs) by drainage status.

	Undrained cropland			Drained cropland		
Crop rotation	**Sediment (Mg ha^{-1})**	**NO_3-N (kg ha^{-1})**	**Total P (kg ha^{-1})**	**Sediment (Mg ha^{-1})**	**NO_3-N (kg ha^{-1})**	**Total P (kg ha^{-1})**
Canisteo-Nicollet-Glencoe (CNG)						
Corn, CT	5.5	0.5	73.9	4.9	16.2	70.0
Corn, RT	3.1	0.5	54.9	2.8	21	55.7
Soy, CT	3.7	0.8	50.3	3.4	1.3	49.9
Soy, RT	2.8	1.7	57.1	2.5	4.2	64.3
Wheat, CT	3.7	1.4	61.4	2.7	24.4	56.1
Wheat, RT	2.1	2.3	59.7	1.4	21.5	48.0
SRWC, CT	1.8	1.6	34.2	0.4	10.6	14.4
SRWC, RT	0.6	1.6	9.2	0.1	10.7	12.4
Grass	0.1	0.1	16.2			
Lester-Hawick-Terril (LHT)						
Corn, CT	135.0	0.7	912.2	103.6	23.8	873.6
Corn, RT	85.8	0.7	829.6	67.0	32.8	906.5
Soy, CT	99.2	0.6	814.4	66.7	4.5	668.7
Soy, RT	74.5	1	973.4	57.3	7.9	881.1
Wheat, CT	85.4	0.5	797.0	45.7	34.7	615.4
Wheat, RT	52.6	0.9	801.8	20.0	33.8	360.1
SRWC, CT	40.4	1.7	368.0	11.8	14.3	161.4
SRWC, RT	10.2	1.7	181.6	4.9	14.7	96.2
Grass	1.2	0.2	36.3			
Lester-Cordova-Canisteo (LCC)						
Corn, CT	10.4	0.2	22.3	10.2	9.1	20.9
Corn, RT	7.1	0.1	17.9	7	1.41	17.9
Soy, CT	10.1	0.4	19.3	11.1	8.3	22.1
Soy, RT	7.5	1.5	17.1	7.4	11.1	18.1
Wheat, CT	4.6	0.6	9.9	4.3	25.5	10.3
Wheat, RT	2.8	0.3	7.3	2.8	19.6	8
SRWC, CT	3.5	0.1	6.7	0.8	4.1	2
SRWC, RT	0.7	0.1	2.4	0.3	4.1	1.4
Grass	0.1	0.1	1.1			
Chaska-Minneista-Colo (CMC)						
Corn, CT	93.5	13.1	972.3	91.1	18.4	1099.5
Corn, RT	56.1	14.1	757.4	50.2	19.4	754.7
Soy, CT	80.2	1.6	1134.1	84.6	9.6	1081.7
Soy, RT	59.4	1.5	803.9	57	9.9	832.2
Wheat, CT	21	1.2	274.3	62	22	909
Wheat, RT	13.7	2.1	236.7	39.1	16.8	620.4
SRWC, CT	19.6	2.4	185.5	14.1	3.6	207.3
SRWC, RT	2.9	2.5	56.6	11.9	3.6	203.3
Grass	1	4.7	25.7			

Short-rotation woody crops (SRWC) and grass THRUs are included for contrast only; SRWC never replaced grass, and only conventionally tilled SRWC THRUs were included in the main simulation. The suffixes 'CT' and 'RT' indicate conventional and reduced tillage, respectively.

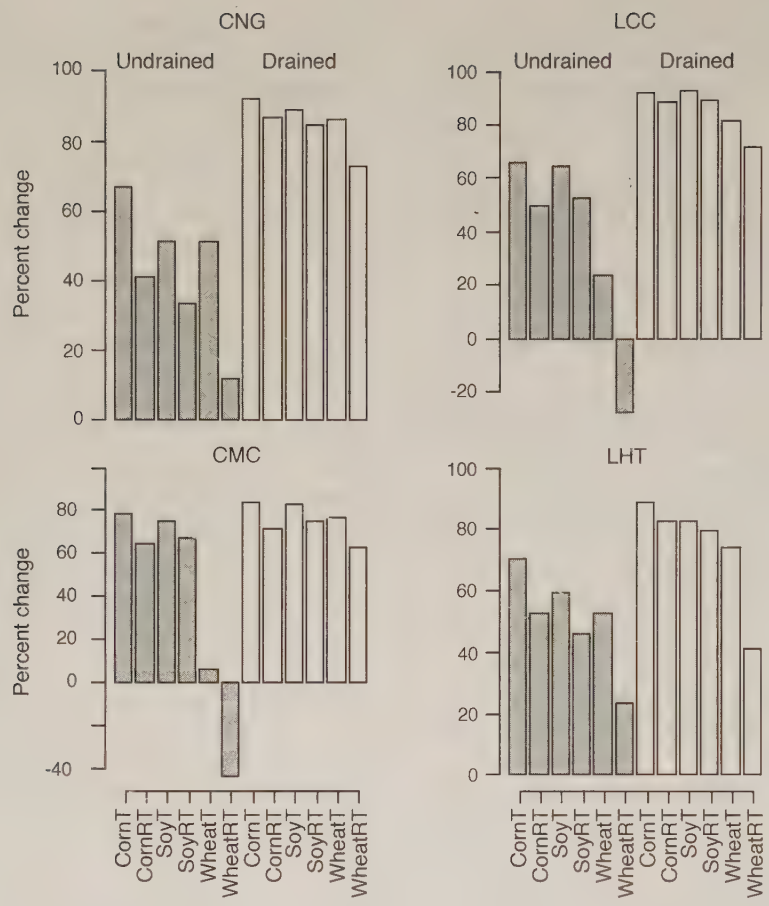

Figure 2. Percent reduction in 5-year modeled sediment yield (Mg ha^{-1}) of short-rotation woody crops (SRWC) relative to other crop/tillage systems, by soil group and drainage status. The suffix 'T' (e.g., CornT) indicates conventional tillage, while 'RT' indicates reduced tillage. The increases in sediment relative to RT wheat on LCC and CMC are probably due to the better ground cover provided by wheat stubble on these poorly drained soils, which are more sloping than CNG soils and finer-textured than LHT soils. See Table 2 for an explanation of CNG, LCC, CMC and LHT.

SRWC THRUs actually exported more dissolved N than corn or soybeans on some of the soil groups. This may be due to lower initial uptake rates by the young trees, or an indirect consequence of litter accumulation, which could result in higher levels of soluble nutrients being held at the surface and thus susceptible to runoff removal. In most cases the ratio of dissolved (as reported in Table 4) to sediment-associated N was at least a factor of 10 higher for SRWCs than for other crops; dissolved plus sediment N export was almost always lower from SRWCs than from any other crop. The model does not report litter accumulation, and the overwhelming influence of rainfall and spring runoff patterns on annual variations in nutrient export made it difficult to document a trend of increasing dissolved N export with stand development; further, such a detailed analysis of model behavior is beyond the scope of this paper.

In sum, the largest overall erosion benefits were realized by replacing corn with SRWCs on either drained or undrained soils, but the picture with respect to nutrients was more complicated. The largest NO_3-N reductions could be realized by replacing wheat on some drained soils, but the largest P reductions tended to result from the replacement of either corn or soybeans, depending on soil and drainage status. To reduce sediment yields, one would certainly want to displace conventionally tilled corn.

Watershed-level effects of SRWC conversion

The effects of 10, 20 and 30% cropland conversion to SRWC on annual runoff, sediment and nutrient delivery at the watershed outlet are summarized in Table 3. The largest proportional reductions in sediment and nitrate yield, which tended to occur in 1997 (a wet year), did not always correspond to the largest reductions in total runoff, which occurred in 2000 (a dry year). During some years sediment and nutrient delivery were actually higher in the SRWC scenarios than they were in the default; this was particularly true of P delivery, which tended to increase following conversion to SRWC. However, under the 20 and 30% conversion scenarios sediment delivery consistently declined relative to the default. It is notable that the greatest incremental reductions in sediment delivery were achieved at the 10 and 20% conversion levels, where the largest

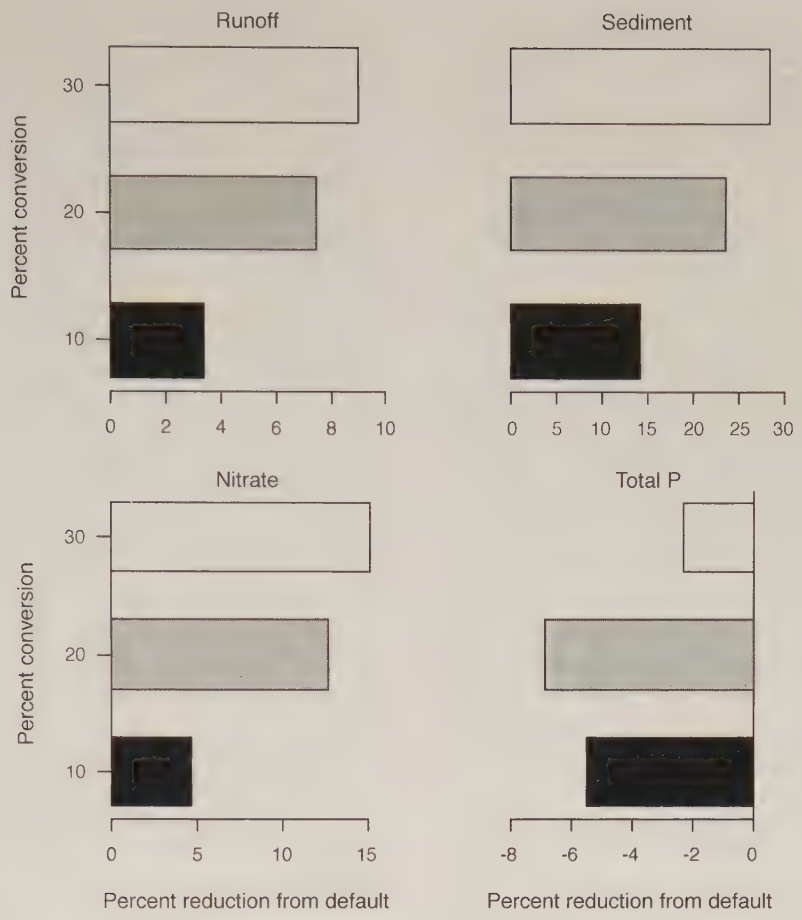

Figure 3. Summary of percent changes in modeled mean annual runoff and loadings (Mg) of sediment, nitrate and phosphorus (P) relative to the default (no short-rotation woody crops, SRWC) watershed condition. 'Percent conversion' refers to the modeled conversion scenario, as in Table 3.

proportion of the most erosive land and crop systems were moved into SRWC production.

Peak flows (annual maximum flow rates, which ranged from 50 to 372 $m^3 s^{-1}$ in the default and from 33 to 373 $m^3 s^{-1}$ in the 30% conversion scenario) did not vary significantly among scenarios ($P_t > 0.05$), but were highest in the default scenario during every year except 1995 and 1998. Annualized standard deviations were higher in 4 of the 6 years in the default scenario, compared to 30% conversion (range 5–24 versus 4–20 $m^3 s^{-1}$), although the differences were not significant, based on pairwise *t*-tests ($P_t > 0.2$). The slight moderating effect of conversion to SRWCs on peak flows, possibly due to their longer growing season and increasing transpirative capacity, supports the conclusions of a 2-year study in the Red River Valley[36], that mature hybrid poplar plantations behave hydrologically more like natural forests than like annual crops. The potential for hydrograph moderation may be an important consideration in flood-prone areas.

Similarly, the differences among scenarios in annual total nutrient and sediment yields were not significant ($P_t > 0.05$). However, the lack of significance may be due in part to the very small sample size (4 points per comparison). Average modeled reductions in sediment yield over the entire rotation ranged from 14% for 10% conversion to 28% for 30% conversion. Mean annual NO_3-N yields fell by up to 15% (Fig. 3). By contrast, mean P yields actually increased by up to 7% following conversion.

Although total P export from SRWC THRUs was generally lower than from other crops, the ratio of dissolved to sediment-associated nutrients (see discussion above) tended to be a factor of 10–100 higher in SRWCs. Because only about 18% of the sediment exported from a field actually enters the stream, dissolved nutrients comprise a much higher proportion of the nutrient load leaving the watershed. Therefore the relative nutrient contribution of SRWC fields to the nutrient load is higher than from fields that export primarily sediment-associated N and P. This would be especially true at the 30% conversion level, in which some drained THRUs were converted to SRWCs. As noted above, the higher relative concentrations of dissolved P and N may result from leaf litter decomposition, since the model parameters were modified to simulate the litter component. Tolbert et al.[8] speculated that increased P export following canopy closure in sweetgum (*Liquidambar styraciflua* L.) plots in

Alabama might be attributable to an increase in the availability of organically bound P in the litter. In sum, the relatively higher dissolved phosphorus and nitrogen losses may partially account for the fact that reductions in sediment yield under SRWCs were much more marked compared to rowcrop HRUs.

Conclusions

The model results unequivocally indicate reductions in peak flows, as well as in annual sediment and nitrate delivery to the Minnesota river, following conversion of agricultural lands to SRWC production. Conversion of at least 10% of the cropland could theoretically produce sediment reductions in excess of the MPCA goal of 10% reduction in 10-year average sediment discharge rates by 2010 for the Minnesota River[37]. However, the goal of a 30% reduction in average NO_3-N discharge would not be achieved under any of the conversion scenarios, although annual reductions as high as 35% were achieved in some years with 30% cropland conversion. While the comparison suffers from incomplete data (the MPCA discharge reductions are relative to 1980–1996 averages, which we did not model), the results do suggest that more comprehensive land use and management changes would have to be implemented to achieve the MPCA goal for this watershed. Conversion to SRWCs with less intensive management, and particularly with lower N fertilization rates, could be more effective in reducing nutrient losses. The acceleration of dissolved nutrient transport by tile drainage may also constrain the beneficial effect of cropland conversion to SRWC.

On the whole, the model results suggest that while cropland conversion to SRWCs may be very effective at reducing sediment delivery to streams, its effect on nutrient delivery will likely be contingent on overall management and by the extent to which drainage remains an important factor in this watershed. Our interpretations of model results were limited by model shortcomings with respect to the simulation of perennial cropping systems. The incorporation of more sophisticated vegetation and crop parameterizations, such as those implemented in the REMM model for riparian zones[38] would substantially improve the usefulness of the model with respect to perennial crops. An additional, and related, issue is the limited ability of ADAPT to properly simulate nutrient movement within and among vegetation compartments, particularly when a perennial below-ground component is involved. Finally, the aggregation of THRUs and the limits of our spatial resolution meant that it was not possible to specify, for example, riparian planting locations for SRWCs. The special functions of forested riparian zones[39–41] make the location of SRWC plantings relative to streams of particular interest, and it would be useful to explore this.

Notwithstanding these limitations, the modeling results with respect to relative changes in nutrient and sediment delivery were sufficiently consistent and robust to be useful for policy guidance. The field-level results highlighted the importance of targeted incentives to optimize the water-quality benefits of cropland conversion to SRWC. Maximum sediment reduction benefits would be derived, for example, from the conversion of conventionally tilled corn on undrained, erosive soils. No-till or reduced-tillage management would further optimize the benefit of conversion: the no-till simulation produced much greater reductions in nutrient and sediment export, relative to the intensively managed SRWC (Table 4).

Policy decisions such as those regarding land-use incentive programs need to be based on the best information available. This project has demonstrated that useful information can be obtained from existing models and data when the resources for complete calibration and re-parameterization of models are not available. At the same time, it is important to recognize that such information can serve only as a qualitative guide.

Modeling results suggest that cropland conversion to SRWCs might be a viable and cost-effective approach to reducing agricultural sediment and nutrient runoff in the Minnesota River watershed. Modeled differences in relative benefits depending on soil type and physiography, as well as on the alternative management system, can provide guidance for possible targeting of incentives to farmers in order to optimize the benefits of cropland conversion.

References

1 CRPD 2001. Short rotation woody crops: a role for the State of Minnesota. Minnesota State University, Center for Rural Policy and Development, Mankato, Minnesota, USA.

2 Vaughan, W., Russell, C., Gianessi, L., and Nielsen, L. 1982. Measuring and predicting water quality in recreation related terms. Journal of Environmental Management 15:363–380.

3 Ribaudo, M., Young, C., and Epp, D. 1984. Recreation benefits from an improvement in water quality at St. Albans Bay, Vermont (Staff Report AGES 840127). USDA Economic Research Service, Natural Resource Economics Division.

4 Henry, R., Ley, R., and Welle, P. 1988. The economic value of water resources: the Lake Bemidji survey. Journal of the Minnesota Academy of Science 53(3):37–44.

5 Jacobson, P., Close, T., Anderson, C., and Kelly, T. 1999. Attitudes of Minnesota residents about fisheries issues. Investigational Report 478. Minnesota Department of Natural Resources.

6 Feather, P., Hellerstein, D., and Hansen, L. 1999. Economic valuation of environmental benefits and the targeting of conservation programs: the case of CRP. Agricultural Economic Report AER 778. USDA Economic Research Service, Resource Economics Division.

7 Ribaudo, M. 1989. Water quality benefits from the Conservation Reserve Program (Agricultural Economic Report AER 606). USDA Economic Research Service.

8 Tolbert, V., Thornton, F., Joslin, J., Beck, B., Bandaranayake, W., Tyler, D., Pettry, D., Green, T., Malik, R., Bingham, L., Houston, A., Shires, M., Dewey, J., and Schoenholtz, S. 1998.

Soil and water quality aspects of herbaceous and woody energy crop production: lessons form research-scale comparisons with agricultural crops. BioEnergy '98—The Eighth National Bioenergy Conference: Expanding Bioenergy Partnerships, 4–8 October 1996, Madison, Wisconsin, USA.

9 Malik, R.K., Green, T.H., Brown, G.F. and Mays, D. 2000. Use of cover crops in short rotation hardwood plantations to control erosion. Biomass and Bioenergy 18:479–487.

10 Licht, L. 1994. Ecolotree buffers strategically planted on Iowa farms for ecological and commercial value. Working Trees: Farming in the 1990's. Owatonna, Minnesota, USA.

11 Udawata, R., Krstansky, J., Henderson, G., and Garrett, H. 2002. Agroforestry practices, runoff, and nutrient loss: a paired watershed comparison. Journal of Environmental Quality 31:1214–1225.

12 High Island Watershed Assessment Project. Available at website http://cgee.hamline.edu/rivers/MRN/HIWAP/ (verified 29 February 2004).

13 Dalzell, B. 2000. Modeling and evaluation of non point source pollution in the Lower Minnesota River Basin. Master's thesis, University of Minnesota, St. Paul, Minnesota, USA.

14 MPCA 1999. Minnesota River Basin Assessment of Stream Water Quality. Based on the 1998 MN 305(b) Report to Congress of the United States. Minnesota Pollution Control Agency, St. Paul, Minnesota, USA.

15 Gowda, P. 1996. An integrated spatial-process model to predict agricultural nonpoint source pollution. PhD thesis, Ohio State University, Columbus, Ohio, USA.

16 Leonard, R., Knisel, W., and Still, D. 1987. GLEAMS: groundwater loading effects of agricultural management systems. Transactions of the American Society of Agricultural Engineers 30(5):1403–1418.

17 Chung, S., Ward, A., and Shalk, C. 1992. Evaluation of the hydrologic component of the adapt water table management model. Transactions of the American Society of Agricultural Engineers 35(2):571–579.

18 Zucker, L. and Brown, L. 1998. Agricultural drainage – water quality impacts and subsurface drainage studies in the Midwest. Bulletin 871. Ohio State University, Columbus, Ohio, USA.

19 Gowda, P., Ward, A., White, D., Baker, D., and Lyon, J. 1999. An approach for using field scale models to predict peak flows on agricultural watersheds. Journal of the American Water Resources Association 35(5):1223–1232.

20 Northern States Power Company 1999. NSP signs biomass contracts with St. Paul Cogeneration, EPS/Beck Power. News Release, 8 January.

21 Minnesota Agricultural Statistics Service 1994. Minnesota Agricultural Statistics 1994. Annual Report. MASS, St. Paul, Minnesota, USA.

22 Minnesota Agricultural Statistics Service 1995. Minnesota Agricultural Statistics 1995. Annual Report. MASS, St. Paul, Minnesota, USA.

23 Minnesota Agricultural Statistics Service 1996. Minnesota Agricultural Statistics 1996. Annual Report. MASS, St. Paul, Minnesota, USA.

24 Minnesota Agricultural Statistics Service 2000. Minnesota Agricultural Statistics 2000. Annual Report. MASS, St. Paul, Minnesota, USA.

25 Isebrands, J., Nelson, N., Dickman, D., and Michael, D. 1983. Yield physiology of short rotation intensively cultured poplars. In E.A. Hansen (compiler). Intensive Plantation Culture: 12 years Research. USDA Forest Service GTR NC–91. p. 77–93.

26 Zavitkovski, J. 1983. Projected and actual biomass production of 2- to 10-year-old intensively cultured *Populus* 'tristis #1'. In E.A. Hansen (compiler). Intensive Plantation Culture: 12 years Research. USDA Forest Service GTR NC–91. p. 72–76.

27 Friend, A., Scarascia-Mugnozza, G., Isebrands, J., and Heilman, P. 1991. Quantification of two-year-old hybrid poplar root systems: morphology, biomass and C distribution. Tree Physiology 8:109–119.

28 DeBell, D., Clendenen, G., Harrington, C., and Zasada, J. 1996. Tree growth and stand development in short-rotation *Populus* plantings: 7-year results for two clones at three spacings. Biomass and Bioenergy 11(4):253–269.

29 Stettler, R., Zsuffa, L., and Wu, R. 1996. The role of hybridization in the genetic manipulation of *Populus*. In R. Stettler, J.H.D. Bradshaw, P. Heilman, and T. Hinckley (eds). Biology of Populus and its Implications for Management and Conservation. NRC Research Press, Ottawa, Canada. p. 87–112.

30 AURI 1997–1998. Short rotation forestry of hybrid poplars. Ag Innovation News. MN 56716. University of Minnesota, Agricultural Utilization Research Institute. Crookston, Minnesota, USA.

31 Ihaka, R. and Gentleman, R. 1996. R: a language for data analysis and graphics. Journal of Computational and Graphical Statistics 5(3):299–314.

32 USGS. Available at Web site http://waterdata.usgs.gov/mn/nwis (verified 29 February 2004).

33 Available at Web site http://www.crh.noaa.gov/ncrfc/documents/MinnRiver.html (verified 29 February 2004).

34 Dalzell, B., Gowda, P., Mulla, D., and Ward, A. 1999. Predicting nonpoint source pollution for a small agricultural watershed in southern Minnesota. 1999 ASAE Annual International Meeting, Paper No. 99–2215. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

35 Licht, L., Schnoor, J., and Nair, D. 1992. Ecolotree buffers for controlling nonpoint sediment and nitrate. Presented at the 1992 International Winter Meeting of The ASAE. Paper No. 92–2626. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

36 Perry, C., Miller, R., and Brooks, K. 2001. Impacts of short-rotation hybrid poplar plantations on regional water yield. Forest Ecology and Management 143:143–151.

37 MPCA 2001. Draft Minnesota River Basin Plan. 18 June2001. Minnesota Pollution Control Agency. Online Document. Available at http://www.pca.state.mn.us/water/basins/mnriver/mnbasinplan.pdf (verified 29 February 2004).

38 Altier, L., Lowrance, R., Williams, R., and Inamdar, S. 1998. The Riparian Ecosystem Management Model: Plant growth component. Proceedings of the First Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada, USA, April. p. 1.33–1.40.

39 Todd, R., Fail, J.Jr., Hendrickson, O.Jr, and Asmussn, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34(6):374–377.

40 Lowrance, R., Leonard, R., and Sheridan, J. 1985. Managing riparian ecosystems to control nonpoint pollution. Journal of Soil and Water Conservation 40(1):87–91.

41 Cooper, J., Gilliam, J., Daniels, R., and Robarge, W. 1987. Riparian areas as filters for agricultural sediment. Soil Science Society of America Journal 51:416–420.

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2. Brink, R.H. Jr, Dubach, P., and Lynch, D.I., 1960. Measurement of carbohydrates in soil hydrolyzates with anthrone. Soil Science 89:157-166.
3. Greenland, D.J., and Szabolcs, I., (eds). 1994. Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK.
4. Arshad, M.A. and Coen, G.M., 1992. Characterization of soil quality: Physical and chemical criteria. American Journal of Alternative Agriculture 7:25-31.
5. Coale, F.J. 1996. Descriptions of the soil test interpretive categories used by the University of Maryland Soil Testing Laboratory. SFM-3. University of Maryland, College Park.

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